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TRANSACTIONS

OF THE

AMERICAN SOCIETY

OF

MECHANICAL ENGINEERS.

VOL. III.

1882.

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SECOND EDITION

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AMERICAN SOCIETY OF MECHANICAL ENGINEERS

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OFFICERS

OF THE

AMERICAN SOCIETY OF MECHANICAL ENGINEERS

1882—1883.

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Cambridgeport, Mass.

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THOMAS WHITESIDE RAE,
HORACE B. MILLER,
C. J. H. WOODBURY.

AMENDED.

[*November 19th*, 1889—*November 17th*, 1891.]

RULES

OF THE

AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

[*Adopted November 5th*, 1884.]

OBJECTS.

ART. 1. The objects of the AMERICAN SOCIETY OF MECHANICAL ENGINEERS are to promote the Arts and Sciences connected with Engineering and Mechanical Construction, by means of meetings for social intercourse and the reading and discussion of professional papers, and to circulate, by means of publication among its members, the information thus obtained.

MEMBERSHIP.

ART. 2. The Society shall consist of Members, Honorary Members, Associates and Juniors.

ART. 3. Mechanical, Civil, Military, Mining, Metallurgical and Naval Engineers and Architects may be candidates for membership in this Society.

ART. 4. To be eligible as a *Member*, the candidate must have been so connected with some of the above-specified professions as to be considered, in the opinion of the Council, competent to take charge of work in his department, either as a designer or constructor, or else he must have been connected with the same as a teacher.

ART. 5. *Honorary Members*, not exceeding twenty-five in number, may be elected. They must be persons of acknowledged professional eminence who have virtually retired from practice.

ART. 6. To be eligible as an *Associate*, the candidate must have such a knowledge of or connection with applied science as qualifies him, in the opinion of the Council, to co-operate with engineers in the advancement of professional knowledge.

ART. 7. To be eligible as a *Junior*, the candidate must have been in the practice of engineering for at least two years, or he must be a graduate of an engineering school.

The term "Junior" applies to the professional experience, and not to the age of the candidate. Juniors may become eligible to membership.

ART. 8. All Members and Associates shall be equally entitled to the privileges of membership. Honorary Members and Juniors shall not be entitled to vote nor to be members of the Council.

ELECTION OF MEMBERS.

ART. 9. Every candidate for admission to the Society, excepting candidates for honorary membership, must be proposed by at least three members, or members and associates, to whom he must be personally known, and he must be seconded by two others. The proposal must be accompanied by a statement in writing by the candidate of the grounds of his application for election, including an account of his professional experience, and an agreement that he will conform to the requirements of membership if elected.

ART. 10. All such applications and proposals must be received and acted upon by the Council at least thirty days before a regular meeting, when the Secretary shall at once mail to each member and associate, in the form of a letter ballot, the names of candidates recommended by the Council for election.

ART. 11. Any member or associate entitled to vote may erase the name of any candidate, and may, at his option, return to the Secretary such ballot enclosed in two envelopes, the inner one to be blank and the outer one endorsed by the voter.

ART. 12. The rejection of any candidate for admission as member, associate, or junior, by *seven* voters, shall defeat the election of said candidate. The rejection of any candidate for admission as honorary member by *three* voters shall defeat the election of said candidate.

ART. 13. The said blank envelopes shall be opened by the Council at any meeting thereof, and the names of the candidates elected shall be announced in the first ensuing meeting of the Society, and also in the first ensuing list of members. The names of candidates not elected shall neither be announced nor recorded in the proceedings

ART. 14.—Candidates for admission as honorary members shall

not be required to present their claims; those making the nominations shall state the grounds therefor, and shall certify that the nominee will accept if elected. The method of election in other respects shall be the same as in case of other candidates.

ART. 15. All persons elected to the Society, excepting honorary members, must subscribe to the rules and pay to the Treasurer the initiation fee before they can receive certificates of membership. If this is not done within six months of notification of election, the election shall be void.

ART. 16. The proposers of any rejected candidate may, within three months after such rejection, lay before the Council written evidence that an error was then made, and if a reconsideration is granted, another ballot shall be ordered, at which thirteen negative votes shall be required to defeat the candidate.

ART. 17. Persons desiring to change the class of their membership shall be proposed in the same form as described for a new applicant.

FEES AND DUES.

ART. 18. The initiation fees of members and associates shall be $25, and their annual dues shall be $15, payable in advance. The initiation fee of juniors shall be $15, and their annual dues $10, payable in advance. A junior, being promoted to full membership, shall pay an additional initiation fee of $10. Any member or associate may become, by the payment of $200 at any one time, a life member or associate, and shall not be liable thereafter to annual dues.

ART. 19. Any member, associate or junior, in arrears may, at the discretion of the Council, be deprived of the receipt of publications, or stricken from the list of members, when in arrears for one year. Such person may be restored to membership by the Council on payment of all arrears, or by re-election after an interval of three years.

OFFICERS.

ART. 20. The affairs of the Society shall be managed by a Council, consisting of a President, six Vice-Presidents, nine Managers and a Treasurer, who shall also be the Trustees of the Society.

All past (Ex) Presidents of the Society, while they retain their membership therein, shall be known as Honorary Councillors, and shall be entitled to receive notices of all meetings of the Council

and may take part in any of its deliberations; they shall be entitled to vote upon all questions except such as affect the legal rights or obligations of the Society or its members.

ART. 21. The members of the Council shall be elected from among the members and associates of the Society at the annual meetings, and shall hold office as follows:

The President and the Treasurer for one year; and no person shall be eligible for immediate re-election as President who shall have held that office for two consecutive years; the Vice-Presidents for two years and the Managers for three years; and no Vice-President or Manager shall be eligible for immediate re-election to the same office at the expiration of the term for which he was elected.

ART. 22. A Secretary, who shall be a member of the Society, shall be appointed for one year by a majority of the members of the Council at its first meeting after the annual election, or as soon thereafter as the votes of a majority of the members of the Council can be secured for a candidate. The Secretary may be removed by a vote of twelve members of the Council, at any time after one month's notice has been given him by a majority of its members to show cause why he should not be removed, and he has been heard to that effect. The Secretary may take part in any of the deliberations of the Council, but shall not have a vote therein. His salary shall be fixed for the time he is appointed by a majority vote of the Council.

ART. 23. At each annual meeting, a President, three Vice-Presidents, three Managers and a Treasurer shall be elected, and the term of office of each shall continue until the end of the meeting at which their successors are elected.

ART. 24. The duties of all officers shall be such as usually pertain to their offices or may be delegated to them by the Council or by the Society. The Council may, in its discretion, require bonds to be given by the Treasurer.

ART. 25. The Council may, by vote of a majority of all its members, declare the place of any officer vacant, on his failure for one year, from inability or otherwise, to attend the Council meetings, or to perform the duties of his office. All such vacancies and those occurring by death or resignation shall be filled by the appointment of the Council, and any person so appointed shall hold office for the remainder of the term for which his predecessor was elected or appointed; *provided* that the said appointment shall not render him ineligible at the next annual meeting.

ART. 26. Five members of the Council shall constitute a quorum; but the Council may appoint an Executive Committee, or business may be transacted at a regularly called meeting of the Council, at which less than a quorum is present, subject to the approval of a majority of the Council, subsequently given in writing to the Secretary and recorded by him with the minutes. Absent members of the Council may vote by proxy upon subjects stated in the call for a meeting, said proxy to be deposited with the Secretary.

ART. 27. The President on assuming office shall appoint a Finance Committee and a Publication Committee and a Library Committee of five members each. The appointment of two members of each Committee shall expire at the end of each year. The Secretary shall, *ex officio*, be a member of all three Committees.

ART. 28.—The Finance Committee shall have power to order all ordinary or current expenditures, and shall audit all bills therefor. No bill shall be paid except upon their audit. When special appropriations are ordered by the Society, they shall not take effect until they have been referred to the Council and Finance Committee in conference.

ART. 29. It shall be the duty of the Publication Committee to receive all papers contributed, to decide which shall be published in the *Transactions*, and which shall be read in full at the meetings.

ART. 30. It shall be the duty of the Library Committee to take charge of the collection of all material for the Library of the Society, and to supervise all regulations for its use.

ELECTION OF OFFICERS.

ART. 31. At the regular meeting preceding the annual meeting a nominating committee of five members, not officers of the Society, shall be appointed, and this committee shall, at least thirty days before the annual meeting, send to the Secretary the names of nominees for the offices falling vacant under the rules. In addition to such regularly appointed committee, any other five members or associates, not in arrears, may constitute an independent nominating committee, and may present to the Secretary, at least thirty days before the annual meeting, all the names of such candidates as they may select. All the names of such independent nominees shall be placed upon the ballot list with nothing to distinguish them from the nominees of the regular committee, and the Secretary shall at once mail the said list of names to each member and associate in the form of a letter ballot, it being un-

derstood that the assent of the nominees shall have been secured in all cases.

ART. 32. In the election of Vice-Presidents, each member and associate may cast as many votes as there are Vice-Presidents to be elected. He may give all these votes to one candidate, or distribute them among more, as he chooses. Managers shall be voted for in the same way.

ART. 33. Any member or associate entitled to vote may vote by retaining or changing the names on said list, leaving names not exceeding in number the officers to be elected, and returning the list to the Secretary—such ballot inclosed in two envelopes, the inner one to be blank and the outer one to be indorsed by the voter. No member or associate in arrears since the last annual meeting shall be allowed to vote until said arrears shall have been paid.

ART. 34. The said blank envelopes shall be opened by tellers at the annual meeting, and the person who shall have received the greatest number of votes for the several offices shall be declared elected.

MEETINGS.

ART. 35. The annual meeting of the Society shall be held on the first Thursday in November of each year, in the City of New York, unless otherwise ordered, at which a report of proceedings and an abstract of the accounts shall be furnished by the Council. The Council may change the place of the annual meeting, and shall, in that case, give timely notice to members and associates.

ART. 36. Other regular meetings of the Society shall be held in each year at such time and place as the Council may appoint. At least thirty days' notice of all meetings shall be mailed by the Secretary to members, honorary members, associates and juniors.

ART. 37. Special meetings may be called whenever the council may see fit; and the Secretary shall call a special meeting at the written request of twenty or more members. The notices for special meetings shall state the business to be transacted, and no other shall be entertained.

ART. 38. Any member, honorary member or associate may introduce a stranger to any meeting; but the latter shall not take part in the proceedings without the consent of the meeting.

ART. 39. Every question which shall come before the Society shall be decided, unless otherwise provided by these rules, by the votes of a majority of the members and associates present, provided there is a quorum.

ART. 40. At any regular meeting of the Society thirteen or more members and associates shall constitute a quorum.

ART. 41. Unless otherwise ordered, papers shall be read in the order in which their text is received by the Secretary. Before any paper appears in the *Transactions* of the Society a copy of the paper shall be sent to the author, and, so far as possible, a copy of the reported discussion shall be sent to every member who took part in the same, with requests that attention shall be called to any errors therein.

ART. 42. The Society shall claim no exclusive copyright in papers read at its meetings, nor in reports of discussions, except in the matter of official publication with the Society's imprint, as its *Transactions*. The Secretary shall have sole possession of papers between the time of their acceptance by the Publication Committee and their reading, together with the drawings illustrating the same; and at the time of such reading, or as soon thereafter as practicable, he shall cause to be printed, with the authors' consent, copies of such papers, "subject to revision," with such illustrations as are needed for the *Transactions*, for distribution to the members and for the use of technical newspapers, American and foreign, which may desire to reprint them in whole or in part. The policy of the Society in this matter shall be to give papers read before it the widest circulation possible, with the view of making the work of the Society known, encouraging mechanical progress, and extending the professional reputation of its members.

ART. 43. The author of each paper read before the Society shall be entitled to twelve copies, if printed, for his own use, and all members shall have the right to order any number of reprints of papers at a cost to cover paper and printing; *provided*, that said copies are not intended for sale.

ART. 44. The Society is not, as a body, responsible for the statements of fact or opinion advanced in papers or discussions, at its meetings; and it is understood that papers and discussions should not include matters relating to politics or purely to trade.

AMENDMENTS.

ART. 45. These rules may be amended, at any annual meeting, by a two-thirds vote of the members present; *provided*, that written notice of the proposed amendment shall have been given at a previous meeting.

CONTENTS OF VOLUME III.

			PAGE
LVII		Proceedings, Philadelphia (Vth) Meeting	1
LVIII	Bayles, James C.	A Tribute to Alexander Lyman Holley	37
LIX		Introductory Remarks and Responses at the Holley Memorial Session.	31 & 51
LX	Trowbridge, W. P.	Determination of Heating Surface required in Ventilating Flues	72
LXI	Webber, Samuel	Efficiency of Turbines, as affected by Form of Gate	84
LXII	Egleston, Thomas	The Appointment of an U. S. Government Commission of Tests of Metals and Constructive Materials	86
LXIII	Bond, Geo. M.	A Standard Gauge System	134
LXIV	Robinson, S. W.	Thermo-Dynamics of Certain Forms of the Worthington and other Compound Pumping Engines	141
LXV	Hoadley, J. C.	The Specific Heat of Platinum, and the use of the Metal in the Pyrometer	187
LXVI	Eckart, W. R.	Chronograph for Engineering Purposes, with the Hipp Escapement.	197
LXVII	See, Horace	Built-up Work in Engine Construction	200
LXVIII	Fraley, F.	An Essay on Mechanics, and the Progress of Mechanical Science, 1824 to 1883, with Introduction by Coleman Sellers	213
LXIX	Auchincloss, W. S.	Averaging Machines	220
LXX	Du Faur, A. F	Expansion of Steam and Water without Transfer of Heat	223
LXXI	Edison, T. A. / Porter, C. T.	Description of the Edison Steam Dynamo	233
LXXII	Hutton, F. R.	Note on the Action of a Sample of Mineral Wool used as a Non conductor around Steam Pipes	244
LXXIII	Trowbridge, W. P.	On a Theorem of Rankine Relating to the Economy of Single-acting Expansion Engines, first published in 1851	252
LXXIV	Thurston, R. H.	On the Several Efficiencies of the Steam Engine, and on the Conditions of Maximum Economy	262

PAGE

LXXV.....Coon, J. S.....Report of a Trial of Upright Boilers and Worthington Compound Pumping Engine at Roxbury Pumping Station..... 309

LXXVI..... .Wolf, A. R..... .Note on the Economy of the Windmill as a Prime Mover..... 319

[PRESENTED BY TITLE, OR READ BUT NOT PUBLISHED]. PAPERS AS FOLLOWS:

LXXVII.....Curtis, Gram *.....Spring-face for Poppet Valves.....

LXXVIII.....Root, J. B.†.....Screw Propulsion (*Second paper*).....

LXXIX. .....McElroy, Samuel.....Steam and Air Economy.....

LXXX.. .....Gorringe, H. H.....Steel Ships and Modifications of Models to Meet the Requirements of the Ocean Carrying Trade .....

LXXXI.....Smith, Oberlin ‡.....The Positions of Views upon Mechanical Drawings .....

LXXXII.....Nagle, A. F.....Feed-Water Heater Performance ...

LXXXIII.....Lanza, Gaetano §.....The Strength of Wood Columns as Determined at the Watertown Arsenal .....

LXXXIV.....Robinson, S. W.|.....The Strength of Members of Wrought-iron and Steel Bridges..

LXXXV .....Johnson, William ¶ ...The Fly-wheel .....

LXXXVI.....Sperry, Charles.....Corrosion of the Propeller-shaft of the S. S. *City of New York* .. ...

LXXXVII....Partridge, W. E.....Determination of the Capacity of the United States Standard Gallon...

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* Republished in full, *American Machinist*, June 3, 1882.

† " " abstract, *Mechanics*, April 29, 1882.

‡ " " full, *Mechanics*, May 20, 1882, and *American Machinist*, May 13, 1882.

§ " " " *Jour. Franklin Inst.*

| " " " *Van Nostrand's Mag.*, Vol. XXVI., No. 5, p. 401.

¶ " " " *American Machinist*, May 13, 1882.

LIST OF ILLUSTRATIONS, VOLUME III.

FIG.		PAGE
1.	Model to show action of belts	25
2.	Diagram of heating coil in flue	82
3.	" " test of water-wheels	faces 86
4.	" " proportion of water used by wheels	86
5.	" " " " " "	86
6.	" " compound engine cylinders	143
7.	" " " " "	145
8.	" " indicator card	147
9.	" " " "	164
10.	" " " "	175
11.	" " " "	178
12.	" " " "	180
13.	View of Woolf tandem engine	181
14.	Section of " " "	183
15.	Diagram of Woolf tandem engine	184
16.	View of receiver compound pumping engine	faces 187
17.	Diagram of specific heat of platinum	189
18, 19.	Chronograph with Hipp escapement	faces 208
20–22.	" diagrams from pumping engine	" 208
23.	Built up work in marine engines	" 212
24, 25.	Averaging machines	220, 221
26.	" "	222
27.	Diagram of expansion	225
28.	" " proportions of steam and water	faces 232
29–35.	Details Edison–Porter steam dynamo	" 242
36.	Diagram of efficiency of engine	279
37.	" " "	286
38.	Curves of efficiency of actual engines	faces 306
39.	" " best angles for windmill blades	" 326

PROCEEDINGS

OF THE

PHILADELPHIA MEETING, 1882.

LVII.

PROCEEDINGS

OF THE

AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

FIRST REGULAR MEETING OF 1882,

PHILADELPHIA, PA., APRIL 19TH-21ST.

THE first regular meeting of 1882 of the American Society of Mechanical Engineers was held in the Lecture-room of the Franklin Institute, Philadelphia, Pa., April 19th, 20th, and 21st.

The meeting was called to order at 10 A.M., April 19th.

The following members and guests were present:

Joseph J. Adams,	New York City.
John F. Allen,	New York City.
William S. Auchincloss,	Philadelphia, Pa.
Stephen W. Baldwin,	New York City.
J. Sellers Bancroft,	Philadelphia, Pa.
William M. Barr,	Cleveland, Ohio.
Charles A. Bauer,	Springfield, Ohio.
James C. Bayles,	New York City.
Alfred Betts,	Wilmington, Del.
George M. Bond,	Hartford, Conn.
Elwood Burdsall, Jr.,	Port Chester, N. Y.
A. Hamilton Campbell,	Elizabeth, N. J.
A. C. Christensen,	Brooklyn, N. Y.
Thomas L. Churchill,	Boston, Mass.
John W. Cloud,	Altoona, Pa.
C. C. Collins,	Erie, Pa.
Aug. W. Colwell,	New York City.
George N. Comly,	Wilmington, Del.
J. S. Coon,	Cambridgeport, Mass.
Charles W. Copeland,	New York City.
Alfred B. Couch,	Philadelphia, Pa.
William Cowles,	Newburgh, N. Y.
Eckley B. Coxe,	Drifton, Luzerne Co., Pa.
Gram Curtis,	New York City.
R. H. Davies,	Phœnixville, Pa.

E. F. C. Davis, ... Pottsville, Pa.
Charles P. Deane, ... Holyoke, Mass.
James E. Denton, ... Hoboken, N. J.
W. W. Drummond, ... Louisville, Ky.
Thomas Egleston, ... New York City.
Albert H. Emery, ... New York City.
A. Faber du Faur, ... New York City.
John Fritz, ... Bethlehem, Pa.
John J. Grant, ... Flushing, N. Y.
Robert Grimshaw, ... Philadelphia, Pa.
H. S. Hayward, ... Jersey City, N. J.
F. F. Hemenway, . . . New York City.
Gustavus C. Henning, ... Baltimore, Md.
William Hewitt, ... Trenton, N. J.
J. C. Hoadley, ... Lawrence, Mass.
J. F. Holloway, ... Cleveland, Ohio.
Robert W. Hunt, . . . Troy, N. Y.
Frederic R. Hutton, . . New York City.
William Johnson, . . . Lambertville, N. J.
Washington Jones, . . . Philadelphia, Pa.
William Kent, ... Pittsburgh, Pa.
William A. Leavitt, ... Philadelphia, Pa.
W. Barnet Le Van, . . . Philadelphia, Pa.
George B. Mallory, . . . New York City.
Professor William D. Marks . . Philadelphia, Pa.
Samuel McElroy, . . . Brooklyn, N. Y.
William Metcalf, . . . Pittsburgh, Pa.
Alexander Miller, . . . New York City.
Horace B. Miller, . . . New York City.
Lycurgus B. Moore, . . . New York City.
Charles H. Morgan, . . . Worcester, Mass.
Joseph Morgan, Jr., . . . Johnstown, Pa.
A. F. Nagle, ... Providence, R. I.
Knight Neftel, ... New York City.
C. C. Newton, . . . Philadelphia, Pa.
William E. Partridge, . . New York City.
Franklin Phillips, . . . Newark, N. J.
George H. Phillips, . . . Newark, N. J.
Thomas R. Pickering, . . . Portland, Conn.
David W. Pond, ... Worcester, Mass.
Charles T. Porter, . . . Philadelphia, Pa.
Francis A. Pratt, . . . Hartford, Conn.
Thomas Whiteside Rae, . . New York City.
Charles B. Richards, . . . Philadelphia, Pa.
Francis H. Richards, . . . Springfield, Mass.
S. W. Robinson, ... Columbus, Ohio.
John B. Root, ... New York.
William J. Root, . . . Brooklyn, N. Y.
W. K. Seaman, . . . Scranton, Pa.
Horace See, . . . Philadelphia, Pa.
Coleman Sellers, . . . Philadelphia, Pa.

William Sellers,	Philadelphia, Pa.
Oberlin Smith,	Bridgeton, N. J.
Henry F. Snyder,	Watsontown, Pa.
Allan Stirling,	New York City.
George S. Strong,	Philadelphia, Pa.
Ambrose Swasey,	Cleveland, Ohio.
John E. Sweet,	Syracuse, N. Y.
Robert H. Thurston,	Hoboken, N. J.
William P. Trowbridge,	New York City.
W. E. Ward,	Port Chester, N. Y.
J. Burkitt Webb,	Ithaca, N. Y.
William Oliver Webber,	Lawrence, Mass.
George W. Weeks,	Clinton, Mass.
W. H. Weightman,	New York City.
Samuel T. Wellman,	Cleveland, Ohio.
Joseph J. White,	Philadelphia, Pa.
Moses G. Wilder,	Philadelphia, Pa.
William H. Wiley,	New York City.
Alfred R. Wolff,	New York City.
C. J. H. Woodbury,	Boston, Mass.

THE PRESIDENT: I have to report to the Society in opening, very nearly as I have to do at almost every meeting, that the membership is rapidly increasing. We have to-day on our list two hundred and ninety-four members, and twenty-two have been passed by the Council and are ready for balloting, so that the membership of the Society has become to-day three hundred and sixteen. It is a very remarkable growth for so young an association; and in other respects the Society is as prosperous as could be desired. We have a new catalogue, which includes membership up to the date of the issue of the last year's catalogue, and when the ballots have been counted to-day a circular will be issued by the Secretary including the names of those who have been passed and successfully balloted for, and which can be added by the members to their catalogues, and which will thus make the list complete up to the end of this session. The applicants balloted for to-day will become members, of course, immediately after the business is transacted, and will join us during our meetings and discussions.

One grand event that has occurred since the last meeting has been the incorporation of the Society. The Society is now incorporated under the laws of the State of New York. The date of incorporation is 1881, as you will find on the Society's seal.

The catalogue lately issued embraces, you will find, one or two new features, to which I wish to call the gentlemen's attention. You will find a list of the past officers of the Society, and also the names of our deceased members, Henry Rossiter Worthington and Alexander Lyman Holley. It was thought by the Council advisable to put on record the fact that those members had been not only distinguished members, but also that they were among the founders of the Society, and their names will be kept on this list as honorary members *in perpetuum*. I imagine that no objection will be made, and that those names will always stand, and, of course, our only regret is that such gentlemen cannot be made honorary members whilst living. The provisions of our Rules are such as to prevent the putting on the honorary list of the names of any members in active professional business, so that neither of these gentlemen could be made an honorary member before his decease.

In the programme for to-day we have general business, presentation of papers, and discussions, for this morning, and a memorial session this afternoon in honor of Mr. Holley. That action was taken by the Society partly because of their own views of its fitness, and largely because a similar action had been initiated by the other great engineering societies of the country. Those societies had already appointed committees to take cognizance of the death of Mr. Holley, and as Mr. Holley was one of the active members of the committee forming this Society originally, our indebtedness to him, and our memory of him, should be stronger than in the case of other societies. The action of the committee appointed by the several societies will be presented to us this afternoon, and the Council have appointed this afternoon as the time for holding such a session. Instead of an evening session we attend a reception given to the Society by members residing in the city of Philadelphia, and by other citizens of Philadelphia.

A committee was appointed by the Society, in conjunction with the other societies, the Society of Civil Engineers and the Institute of Mining Engineers, on the advisability of making efforts to secure the restoration of the United States Board appointed some years ago for the testing of iron, steel, and other materials, in the same or some other form, and the

Council considered this of such importance that they set it on the programme as the object of a special meeting, so that you will find on the programme that one afternoon is devoted principally to the discussion of that subject. The afternoon of Friday is given to the consideration of urging the passage of the bill now before Congress for the re-formation of the Board to test the materials of construction. That whole matter will be laid before you by the chairman of the committee, and the way in which it is proposed to operate will be suggested, and the subject will be then open for your discussion. The action of the committee must depend upon the action of the Society.

Should time permit, after that matter is disposed of, we will go on to our regular work of the reading and discussion of papers. We have on our list twenty-two papers It is hardly worth while reading the titles of them all. Mr. Rae will put on the board a sufficient number of these papers to furnish a day's work, so that we can have some idea of when each one will come up. There are also presented two papers which will be put on the list, if the Society has no objection, by candidates for membership ; those of Professor Webb, of Cornell University, and Professor Lanza, of the Massachusetts Institute of Technology. If we can make such progress as to get to them they will be read on Friday. The Secretary particularly desires that members should make it a point to enter their names on the register, with the places at which they are stopping in the city. Then that list will be of service to the members of the local committee who wish to know for whom to get passes. Mr. Le Van informs us that he can get a reduction of prices at hotels for some of the gentlemen here. The Secretary has a collection of guests' badges, and gentlemen who are guests of the Society are requested to call upon him and obtain them, which will identify them as guests of the Society. Gentlemen will also find in the hands of the Secretary a set of cards, which will be found useful as cards of introduction to any point of interest. They will also serve as cards of identification if you are unknown to members of the committee. You will also find a programme of the excursion by water in the hands of the Secretary, and at intervals between sessions he will be ready to distribute all these cards and programmes. Those who wish to go to other

places than those on the committee's list, can obtain escort if they desire. The local committee have made arrangements to provide escorts for those members who are strangers here.

The Secretary also wishes me to state that the bound volume of the Transactions for 1880 is now ready and members can have them The papers for 1881 will be ready for use before the end of the session. The papers of the last meeting are in press, and will probably be in our hands before we adjourn.

There are a number of special committees appointed by the Society, and I would ask those gentlemen who are interested in the matters of which those committees take cognizance to communicate with them, and assist, so far as they can, in the work of those committees. The first is the Committee on Permanent Location of the Society; Professor Trowbridge is chairman, and Messrs. Copeland, Egleston, Merrick, and Hoadley are the other members. The object in appointing that committee was to make provision for the permanent location of the Society. The Society of Civil Engineers has a house in New York, which it now owns. The Institute of Mining Engineers has no headquarters, and it is at a great disadvantage for that reason, and it is the hope of members of those two societies and of this Society, with whom I have talked on the subject, that in the course of time the three may unite in putting up a building, probably in the city of New York, which will be the headquarters of the members in the city. That being done, it will form a centre for the engineering interests of the whole country. That is the scheme which the Committee on Permanent Location has in hand, and Professor Trowbridge will be always glad to receive suggestions, and he and the other members will always be pleased to talk with members of the Society with regard to the best way of accomplishing that result.

There was appointed some months ago, as the members will remember, a joint committee on the invitation of foreign engineers to this country. That scheme was largely the proposal of our friend Holley, and last summer the joint committee—this was a joint committee of the societies of Mining, Civil, and Mechanical Engineers—appointed a sub-committee, consisting of Mr. Holley, of our Society, and Mr. McDonald of the

Society of Civil Engineers, to go abroad and sound the waters on that side, and the idea was that we might possibly get the whole scheme inaugurated, and have the work of this committee completed, so that an excursion could be formed of engineers visiting this country from Europe some time during the coming summer. The gentlemen went abroad, and Mr. Holley's ill health left Mr. McDonald to do the work, practically, and it was found that the times were not ripe for it, and the matter is indefinitely deferred. But the attitude taken by members of the profession over there was not precisely what was desired by our members. There seemed to be a little feeling that there might be some selfish interests involved, and it was concluded to lay the matter aside for awhile, and after a time, when it has been thoroughly talked over in this country and there, I have no doubt that on both sides we shall find the liveliest interest taken in the scheme.

The special Committee on Tests of Iron and Steel we have already spoken of. Of that committee, Professor Egleston is chairman, and Messrs. Leavitt, Metcalf, Oberlin Smith, and Woodbury, are the members, and at the special session to be held, at which that matter will be considered, it will be expected that all members at all interested in the subject will give us their ideas, and enable that committee to form such resolutions, and take such action as will be most effective, and meantime you will find those gentlemen ready to consult with other members in reference to the best way of accomplishing the work.

We also have a self-constituted committee at Pittsburgh. Mr. Lawson has been experimenting there upon steam-boilers, and has obtained some results which are probably valuable and interesting, and several members of our Society living in Pittsburgh, were requested to constitute themselves a committee to attend at these experiments, and report to the Society if they should find anything valuable there. Those gentlemen are William Metcalf, chairman, Reuben Miller, Joseph Reese, F. W. Gordon, James Park, Jr., and James P. Witherow. I hope we may get something of value from them relating to that series of experiments.

The reports of officers are required at annual meetings, but I may say that the Secretary gives us a report that he has informally rendered with regard to the members etc. The

Treasurer makes a report very similar to that of last fall, stating that he has some two thousand dollars in government bonds, and several hundred dollars of cash on hand, and that he is receiving a very large percentage of dues. There is nothing to indicate that we are going to lose anything in either members or dues.

There are no amendments of our Rules to come up at this meeting. They all pass over to the annual meeting, where only they can be considered.

The first business in order is the reading of the minutes of the last meeting.

On motion of Mr. Washington Jones, the reading of the minutes of the last meeting was dispensed with.

THE PRESIDENT: The next business in order is the counting of ballots by tellers.

On motion of Mr. Jones it was agreed that tellers should be appointed by the chair.

The chair appointed Messrs. Jones, Weightman, Miller, and Henning, tellers.

THE PRESIDENT: If there is no other business, we will proceed at once to the reading of papers. The first step in connection with papers, is the discussion of those which have been deferred to this meeting. There were two or three that were laid over from the last meeting for discussion. It was hoped that members would have time to think about the subjects, and be prepared to discuss them at this meeting, and the Council have directed that it shall be in order for any member to call up any paper that has been heretofore printed, when it is thought that discussion has not been complete, or where new matter can be presented. The order in which we shall read these papers will be dependent largely upon the state of readiness in which we can find them. The first paper is by Mr. Eckart, on the "Chronograph for Engineering Purposes, with the Hipp Escapement." Mr. Eckart is not present, but the Secretary has his paper and will read it.

Mr. Eckart's paper was then read by the Secretary.

PROFESSOR THURSTON then read a paper on the "Several Efficiencies of the Steam-engine."

THE PRESIDENT: The tellers report that the whole number of votes cast was one hundred and seventy-one, and that all the candidates were duly elected. Their names are as follows;

MEMBERS.

Charles H. Loring, . Chief Engineer U. S. N., Navy Yard, Brooklyn, N. Y.
Thomas F. Rowland, . . Continental Iron Works, Greenpoint, N. Y.
W. R. Eckart, ... P. O. Box 1587, San Francisco, Cal.
John B. Root, ... Abendroth & Root Mfg. Co., Greenpoint, N. Y.
William T. Leman, ... 305 West 55th Street, New York City.
Walter E. Parker, ... Lawrence, Mass.
Maunsel White, ... Bethlehem, Pa.
William Johnson, . . Supt. Lambertville Iron Works, Lambertville, N. J.
David W. Payne, ... Corning, N. Y.
H. C. White, ... Hartford Engineering Co., Hartford, Conn.
Julius L. Hornig, ... Jersey City, N. J.
John M. Hartman, . . . 1237 N. Front Street, Philadelphia, Pa.
T. W. Hugo, ... Duluth, Minn.
J. H. Burnett, ... 80-82 Reade Street, New York City.
J. S. Lane, . . . Webster, Camp & Lane Machine Co., Akron, Ohio.
Albert W. Stahl, Engineer Corps, U. S. N., Navy Dept., Washington, D. C.
A. E. Leavitt, ... Hartford, Conn.
F. H. Underwood, ... Tolland, Conn.

JUNIORS.

Isaac Chase Greene, ... P. O. Box 846, New York City.
W. Irving Babcock,
Delaware River Iron Shipbuilding and Engine Works, Chester, Pa.
Andrew J. Caldwell,
Hydraulic Works, Van Brunt & Rapelye Streets, Brooklyn, N. Y.
Lienau Walden, ... 430 Walnut Street, Philadelphia, Pa.

The session was then adjourned to 2.30 P.M.

Afternoon Session.

The President: The special business of the afternoon, the holding of a Holley Memorial Session, was arranged by the Council on the receipt of communications, as I stated this morning, from the sister societies. Those societies, having appointed committees with reference to this matter, requested that our Society should also appoint a committee to act with them. The Society of Civil Engineers appointed Messrs. Macdonald, Hamilton, Chanute, and Clark. On our part Messrs. Trowbridge, Bayles, Gordon, Coxe, and Hunt, were appointed. The Mining Engineers appointed Messrs. Raymond, Griswold, Prince, and others yet to be named. The records of that joint meeting are on the table, and I will ask the Secretary to read them.

The Secretary then read the records of the joint meeting as follows:

A meeting of representatives of the three committees appointed by the "Civil," "Mining," and "Mechanical" Engineers, to consider what steps should be taken to prepare a memorial to the late Alexander Lyman Holley, was held at the Westminster Hotel, on the evening of March 22d, 1882.

There were present of the "Mining" Engineers, Dr. R. W. Raymond; of the "Mechanicals," Mr. J. C. Bayles, and Professor W. P. Trowbridge; of the "Civils," Messrs. W. G. Hamilton, O. Chanute, T. C. Clarke, Charles Macdonald, and, informally, Mr. J. P. Davis, of the "Board of Direction" of the Civil Engineers.

It was moved and carried "that the committees of the three societies act as a *joint committee*."

Of this joint committee Dr. Raymond was elected chairman, and Mr. Macdonald secretary and treasurer.

It was moved and carried, "That Dr. Raymond be requested to deliver a 'Memorial Address' before an assembly of the three societies, at some future occasion to be decided upon."

A discussion ensued as to the time of holding such an assembly. It was thought that it should not be earlier than the next fall.

It was moved and carried, "That a sub-committee of one from the committee of each society be appointed for the purpose of collecting information, etc., as to the nature and location of a 'Memorial,' and time of proposed joint meeting, and any other necessary details, with instructions to report, with recommendations, to the joint committee."

The members of the sub-committee appointed under the above resolution were Dr. Raymond, "Mining Engineers;" Mr. Bayles, "Mechanical;" and Mr. Macdonald, "Civil."

A general discussion ensued as to the probable cost of a suitable "Memorial," to be erected in Central Park, New York. It was thought that $10,000 would be ample for the purpose, and it was moved and carried, "That the sub-committee be authorized, if they found on inquiry that a bust or monument could be put up in Central Park for $10,000, to solicit subscriptions at once without reporting to the joint committee, and that such subscriptions should not be confined to members of the three societies."

A discussion was then had on the publication of a "Memorial Book," containing the Memorial Address, and a comprehensive review of Mr. Holley's life and work.

The members of the separate committees were requested to lay the subject before their societies for further instructions.

Adjourned, to meet at the call of the Chairman.

THE PRESIDENT: That committee have arranged—I think the arrangement is complete—with Dr. Raymond to deliver a Memorial Address before the three societies jointly. I presume that will occur about the time of our annual meeting in the fall. Dr. Raymond requires time for preparation, and I presume it will take time to arrange for a joint meeting. In the meantime, each of the societies has taken some such action as it has been proposed to take this afternoon, and the Council have appointed the afternoon for some special action here. The business of the afternoon is the action of the Society upon this matter as presented by the committee which have delegated one of their number to represent them, and before calling upon that gentleman to speak to us I will read what is, so far as I know, the last communication to this Society from Mr. Holley. At the death of Mr. Worthington, Mr. Holley was appointed to write a few words *in memoriam*, and they were printed, but were never formally presented to the Society. Here the President read Mr. Holley's "IN MEMORIAM" of Mr. Worthington, published in the Transactions of the Second Regular Meeting of 1881, and after some feeling, prefatory words introduced Mr. James C. Bayles, who delivered the Memorial Address.

THE PRESIDENT: The committee present a series of resolutions for the action of the Society, which I will ask the Secretary to read.

The Secretary then read the following resolutions:

WHEREAS, We are called upon as a society to give expression to profound and sincere sorrow in the death of our Vice-President and friend, Alexander L. Holley:

Resolved, That we mourn the death of our friend as an irreparable loss to the profession, and as a sad personal bereavement.

Resolved, That in the death of Alexander L. Holley the country has lost an engineer whose genius and industry have greatly aided our industrial development, and to whom all branches of the engineering profession were profoundly indebted.

Resolved, That we shall ever hold Alexander L. Holley in cherished remem-

brance, as one whose life and example are an inspiration to high views and worthy motives, and who gave a new dignity to all branches of our profession; and that we remember our associations with him as something which made our lives happier and our work lighter.

Resolved, That the Secretary be directed to forward a copy of these resolutions, with the report of our memorial services, to the family of Mr. Holley, with assurances of the deep and tender sympathy we feel for them in their bereavement, and that the committee of five appointed by our Council be directed to coöperate with the committees appointed by other societies in furthering the work of securing a worthy and permanent Holley Memorial, in whatever form may be deemed most appropriate and best calculated to keep his work and example before the rising generation of engineers.

The resolutions were unanimously adopted.

Remarks were made upon the theme of Mr. Bayles's tribute, by Messrs. Fernie, Coxe, Hunt, Metcalf, Charles T. Porter, Hoadley, Holloway, C. Sellers, A. H. Emery, and Partridge.

The President: We are here as guests of the Franklin Institute of this city. The Franklin Institute is one of the educational establishments of this country which has done most work on small capital. With the possible exception of the Cooper Institute, of New York, this institution has done more good with a little money, than any other in the world A history of its work has been prepared by Mr. Fraley, of this city, and has been brought in by Mr. Sellers, and will be presented among other papers, and put on our records, if there is no objection on the part of the Society. There seems to be none, and it will be placed on the records.

Mr. Sellers: I wish to say that the origin of this paper was a letter from the President of this Society to me, suggesting the great propriety of some member of the Franklin Institute preparing a paper to show the efforts the Franklin Institute had made to advance the mechanic arts. Now, as Mr. Fraley was among the very few members who were members in the year 1854, and who are now members, I asked him if he would prepare such a paper. He has done so with a great deal of care, and it has been placed in my hands, and it is that which I now give to the President to be read by title, and if it is printed, I should like to preface it with a few remarks, which I will not make now, as to Mr. Fraley's real position, and the part he has played in all this. As one who has been intimate with all those great men who made the Franklin Institute celebrated in its day, his narrative will certainly be of interest to all our mechanics.

PROFESSOR HUTTON: It seems to me that it is only appropriate, since this is a Memorial session, that after the regular tributes have been paid, we should at once adjourn. Otherwise, it might appear in our minutes, perhaps, as if we had rather interpolated a memorial meeting into other business. I would therefore move that we at once adjourn.

Agreed to.

THURSDAY, APRIL 20TH.

MORNING SESSION.

The meeting was called to order at 10 A.M.

THE PRESIDENT: There is no business coming before the Society on my list this morning. We can proceed at once to the reading of papers. But I will say before we take up any papers that the Council considered yesterday, the place and time of the next meeting. After discussion, in view of the fact that we had no invitation for next summer, and of the fact that we are proposing to hold a joint convention with the other two societies, to listen to the memorial services conducted by Dr. Raymond, it was finally concluded that when the meeting adjourns, it shall adjourn to meet at the call of the presiding officer, when the time and place of the joint convention shall be determined upon by the joint committee. I presume the place will be the city of New York, and the time probably the early fall. Dr. Raymond wants to be given ample time for the preparation of his address. It will be somewhat lengthy, and I have no doubt exceedingly interesting, and to do the matter full justice, he wishes to take ample time, and do it with perfect deliberation. So I presume the gentlemen may be expected to be called together some time in the early fall, and most likely in the city of New York, in joint convention with the Society of Civil Engineers and the Institute of Mining Engineers.

The first paper on our list is that of Mr. Coon, entitled, "Results of a Test of Upright Boilers and Pumping-Engine."

MR. COON read his paper.

THE PRESIDENT: I see we have present probably as large an audience as we can expect during the session. If it should occur that the meeting of the joint convention of the societies should be set at a late date, there will not be time for the Nominating Committee to do its work. We are compelled by

our By-Laws to appoint a committee to nominate officers for the succeeding year, and in order that that committee may have ample time for deliberation and correspondence, it should be appointed so early that its deliberations will be neither interrupted nor hurried; and for that reason, it will probably be best to provide for the appointment of the committee now. I suggest to the gentlemen that they determine whether to have the Nominating Committee appointed in the interim, or whether we shall wait till the next session. If it should happen that the joint convention should be fixed for some time in September, there would be a very short interval between that and the November meeting; and the members of the committee of last year informed me that they had not, even then, time enough. The time this year will be very much curtailed. I will make a suggestion, with the approval of the Council, that the direction for the Nominating Committee be made now, in order that it may be appointed in ample time to do its work. I wish to remind members that if they have the interest of the Society at heart, as I have no doubt they all have, they will suggest names to the Nominating Committee, sending their suggestions to the Secretary, addressed to the Nominating Committee. Of course it is expected that those nominated should be men prominent in the Society, for what they have done, or for their interest and work in the Society. I presume it will be found that the coming year will be a very critical year in the history of the Society. The adjustment of finances and the regulation of matters of routine will no doubt be well settled in the course of another year; and I presume gentlemen will understand that we cannot be too cautious in providing a good slate. Will you take action on this matter, gentlemen?

Mr. Weightman: I would make a motion, Mr. Chairman, that the committee be appointed by the presiding officer as usual.

Mr. Kent: I think it would be well if it were settled that the Nominating Committee may transact their business by correspondence; so that the views of a member, say from Indianapolis, could be given the same as if he were present, and that, with the suggestion that all the members of the Society be invited to give their views to the Nominating Committee, will greatly facilitate the performance of its duties.

PROFESSOR SWEET: My connection with that matter justifies me in indorsing what the gentleman has said; and to carry that out it would be of the greatest importance that the committee be nominated early.

THE PRESIDENT: I presume it will be necessary to conduct the business of the committee in that way. We certainly cannot appoint a nominating committee of members who are all at one place. It is certainly at the committee's own option, and I presume it must be understood that their work shall be done by correspondence.

The motion was agreed to.

PROFESSOR ROBINSON read his paper entitled "The Thermodynamics of certain Worthington and other Compound Engines." There was no discussion.

THE PRESIDENT: The next paper is one by Mr. Bond, on "A Standard Gauge System."

MR. BOND read his paper.

PROFESSOR ROBINSON: I would move that, in view of its importance to the profession, a Committee be appointed to avail of the opportunity afforded by the Pratt & Whitney Company to investigate its proposed system of standard gauges, and to make such statement to the Society regarding it as shall be found advisable.

MR. KENT: In the experience of the Institute of Mining Engineers, it was found advisable to adopt the rule never to indorse anything. Since they adopted the rule they have in one or two instances departed from it. But the indorsement of the Society as a society is a matter of very little consequence. What is needed is a report by the committee to the Society stating the committee's judgment. The report of that committee is then published to the world, and the world appreciates the report of that committee far more than it would the judgment or vote of any society. I suggest that the committee simply report to the Society, and let the report be published. I have no doubt that the system of Messrs. Pratt and Whitney is worthy of the highest indorsement. I suppose we have reached the limit now of such investigations; that this is the best work of the kind ever done in the world, and that it will never have to be repeated during our lifetime.

MR. LE VAN: We do not suppose that this Society is infallible, and there will be no harm in making this examination.

If we do not take any action in the matter it may die away, and the results of their experiments will be lost.

The motion was agreed to.

THE PRESIDENT: How will you have the committee appointed?

A MEMBER: By the President.

THE PRESIDENT: If there is no objection, it will be appointed by the President, and any suggestions as to who are the proper men to go on the committee will be in order at any time. A memorandum left with the Secretary will answer the purpose. If there are no other remarks in regard to this matter, we will take up the next paper, which is by Professor Trowbridge, entitled "Determination of the Heating Surface of Ventilating Flues."

PROFESSOR HUTTON: I propose to read this paper in abstract. It is a custom which the Society will have to inaugurate before long. The paper is of a distinctly mathematical character.

Professor Hutton then read the paper.

MR. WOLFF read a paper entitled "Economy of the Windmill as a Prime Mover."

THE PRESIDENT: I would say here that Professor Trowbridge presents another paper, which he desires to be read by title only. It is entitled "Rankine's Theory Relative to the Economy of Steam in the Cornish Engine." The next paper on our list, which is also to be read by title only, is by Mr. Curtis, entitled "A Spring Face for Poppet Valves." The next paper to be read is by Mr. Root, on "Screw Propulsion."

MR. ROOT: This paper is not a statement of results obtained. It is merely a proposition for a change in the principle of applying the propelling power of an engine to the water, for the purpose of propelling vessels. My object, in presenting the paper, is to place the matter before practical engineers, and, if it is wrong in principle, and cannot be made to realize the results that I think it is capable of producing, why, of course, the knowledge of the subject, that may be reasonably looked for in this Society, will be sufficient to ventilate any errors that the paper may contain, which is what, I hope, will be done, if any errors are there.

Mr. Root then read his paper. No discussion was elicited.

The session was then adjourned to 2.30 P.M.

Afternoon Session.

The President called the meeting to order at 2.30 P.M., and Professor Egleston, chairman of the Committee on Tests of Iron, Steel, and other Metals, addressed it, after which discussion ensued:

Professor Egleston: I should be very much obliged to all the members if they would send to the Secretary of the Society what they have said and what they intended to say, so that it may be published in pamphlet form as soon as practicable and distributed among the manufacturers for their education and the education of the persons who represent them in Congress. The calls upon me quite recently for such documents as this have been very frequent. I have been told distinctly by certain manufacturers that they would do the work simply for having the credit of having been interested in getting this commission established. It is, therefore, important that the pamphlet should be got ready as soon as possible for distribution among the manufacturers, who are working not only upon their Congressmen but upon their governors and legislatures, and in some cases with very great effect. The passage of the bill at some time is a matter in which every one of us is interested, and I shall therefore be extremely obliged, as chairman of the committee, if the gentlemen will write out as soon as possible what they said as well as what they intended to say and send it to the Secretary.

Mr. Kent: In connection with Professor Egleston's suggestion, I would like to ask if the stenographer is not taking this discussion, and if it will not be written out.

The President: That will come in due course from the Secretary; but it will probably be some time before it will be ready; not as soon as Professor Egleston desires.

Professor Egleston: It is very important that this should be done as quickly as possible. I spoke of certain manufacturers who are coming to me constantly, and writing to me constantly, saying: "If we only had the information, we could bring about the passage of the bill;" and I am sure the discussion which has taken place this afternoon, even if it did not influence any one, would form an engineering document valuable to all of us.

Mr. Le Van: I am satisfied, Mr. President, that if a copy of

these proceedings were made, it would be very important as emanating from this Society.

PROFESSOR HUTTON: I would like, Mr. President, to offer a resolution of indorsement of the plan proposed by this committee, in order that Mr. Le Van's suggestion may be carried out, that we give the weight of the Society, as far as possible, to this question. I would suggest that the expenses that this committee of our Society may be exposed to,—the expenses for the manifolding of the immediate production of these remarks for correction, and of circulating this memorial,—shall be passed through our Finance Committee. My resolution is: "That we indorse the plan proposed by the committee, and that our Finance Committee be requested to audit and indorse the expenses to which that committee is exposed."

Agreed to.

THE PRESIDENT: The next paper is a paper by Messrs. Edison and Porter, entitled a "Description of the Steam Dynamos in the New York Central Station."

MR. PORTER: It is unfortunate that Mr. Edison cannot be here. He is rather slowly recovering from a very severe illness. It is also matter of regret that we cannot show the dynamo fully by way of illustration, but the best that can be done is to let these views from the *London Engineering* of March 10th be circulated. I have a few copies here representing the machines which were sent to London, and are now running there, and representing those which are now being erected in New York, with slight modifications.

My own knowledge respecting electrical problems is of course superficial, but any questions on that subject that may be asked will be kindly replied to by Mr. Clark, the engineer of the Electric Light Company, who is present.

Mr. Porter then read his paper.

THE PRESIDENT: The next paper is to be read by title only. It is by Mr. Samuel Webber, and is entitled, "Comparison of Turbines." Following that is a paper by Mr. McElroy, on "Steam and Air Economy."

Mr. McElroy then read his paper.

THE PRESIDENT: A paper by Lieutenant-Commander Henry H. Gorringe entitled "Steel Ships and Modifications of Models to meet Requirements of the Ocean Carrying Trade," will be

read by title only. The next paper is by Mr. Hoadley, styled, "Experiments on the Specific Heat of Platinum."

Mr. Hoadley then read his paper. There was no discussion.

Adjourned to 8 P.M.

Evening Session.

The President: I would say, before proceeding to business, that the Council had before it the other day the consideration of the method of disposing of our papers. It seems very probable that we may soon have more papers than we can print, and it has been decided to refer all papers to the Publication Committee, they to determine what papers they can print, which are to be printed in full, which in abstract, and which simply by title. The papers, after being read, are to be transferred by the Secretary to the Publication Committee, and they are then to determine what shall be done with them and hand them back to the Secretary, with directions for his procedure, and he then takes charge of the publication.

Before proceeding with the reading of papers we will take up any business that may be offered.

Mr. Oberlin Smith: *Mr. President:* I rise to make a motion, which I sincerely hope I may have occasion to withdraw, in favor of some other, which shall be *better* calculated to attain the object sought. On the occasion of presenting to you a paper on "Experimental Mechanics" last year, at Hartford, I gave notice of a future motion of this kind. Its object is to make efforts toward a future establishment of some sort of an engineering commission which shall represent the best brains and knowledge of all the great technical schools and societies of America, if possible under the auspices of Government, and of a character to be respected and largely followed by our manufacturers, architects, and engineers.

The work of this commission, as proposed, was, therefore: First, experiment; second, collection, systemization, and distribution of information; third, establishing standards. The first section is of almost infinitely greater magnitude than the others, and of far too great expense for this, or a combination of societies, to attempt alone.

As, however, we are now making a movement (which we all earnestly hope may prove successful), toward the reappointment of the Government Board of Tests, which would be all in

this line that we could at present hope for. I shall limit this motion to the two last sections, which are surely within the near grasp of an earnest effort.

You have, probably, noticed that an actual movement is now under way to establish a national standard for gear-teeth. This much-needed work is being done, unaided, by the same Society which gave us our invaluable system of standard screw-threads,—the Institute whose hospitality we are now enjoying, which bears the name of our "past grand" member, the immortal Franklin.

If a local society can accomplish so much, why should we not go further and give this and other matters the prestige of a national movement? A few such other things, needing immediate attention, are standards for lathe-spindle screws, for lathe-centre tapers, for drill shank-tapers, for counter-shaft belt speed, for exact pipe-threads and hose-couplings, for tap-heads and wrenches, for key-seats, for set-screws, for screw-threads below quarter-inch, for machine-screws, for wire-gauges, for bolt-slots and pin-holes in planers, for holes in milling cutters, for dowell-pins, etc., etc.

Therefore, Mr. President, in order to bring this matter into a practical shape for discussion, I move that the Chair appoint a committee to confer with technical schools and with other societies regarding the feasibility of uniting in establishing a national bureau of information and standards, the committee to report at a future meeting.

Mr. Bond: I second the motion.

The President: Would there be any objection to a reference of that to the committee already formed?

Mr. Smith: It would be an excellent idea.

The President: Would you modify your motion that way?

Mr. Smith: Yes, sir; I would be glad to do so. I have not studied the matter much. I wish somebody would say something about it. What was the exact duty of that committee?

The President: Simply to examine the system of standards proposed by Pratt and Whitney, and their method of operation, and to report to the Society, and it is just as well to make that either a temporary or standing committee, and let them take charge of the whole subject of standards. Your resolution can be made to cover that. If you choose to give it that shape it can be done readily.

MR. SMITH: I might add, "and that it be referred to the Committee on Standards and Gauges," already appointed.

THE PRESIDENT: That this duty be referred to that committee?

MR. SMITH: That the Chair appoint a committee or refer the matter to a Committee on Standard Measurements already appointed.

THE PRESIDENT: That would do it.

Motion agreed to.

PROFESSOR HUTTON: *Mr. President:* That brings me to a point which I was proposing to bring before the Society. When Mr. Smith began his motion I thought it was, perhaps, going to cover what I wanted to bring out. It is part of our duty, no doubt, to establish standards and gauges. The motion of Mr. Smith and my motion look towards the establishment of gauges in mechanical things which are measurable. It has occurred in my own practice that there is no one unit which we handle so frequently and about which there is such a degree of uncertainty as what is technically known as the horse-power of boilers. Personally I have been almost what, in the vernacular we should call "badly left," because I considered the horse-power of a boiler to be about equivalent to the evaporation of about thirty-five pounds of water per horse-power per hour. Thirty pounds of water evaporated to the hour is the standard in acceptation in certain parts of the country. Now it has struck me that in slide valve practice, and in a good deal of our practice, thirty pounds of water per horse-power per hour is not quite margin enough, and would not this Society of Engineers do a great deal if they could establish, either by experiment or by investigation of current practice, what significance we shall attach to that term of the horse-power of boilers? It is a ridiculous expression, but it has got into our terminology, and into our contracts, and it has become fixed. My idea was, therefore, Mr. President, that the Chair should appoint a special committee for the consideration of this subject, say of five, to report at a future meeting upon the subject of the mechanical engineers' standard of what should be the horse-power of a boiler. I would make a motion, therefore, that the Chair appoint a committee of five to report to the Society on that subject

MR. NAGLE: *Mr. President:* Professor Hutton will find this

whole subject of the horse-power of boilers most thoroughly and exhaustively treated in some of the back numbers of the *Franklin Institute Journal*, and it is my opinion that all that can be said upon the subject is already in print, and can be found in the literature appertaining to engineering, and therefore I see no occasion for the appointment of another committee. In view of these facts I should vote against the resolution. I might add that the Supreme Court of Massachusetts has decided that there is no recognized standard for horse-power of boilers, by which the purchaser or seller can be governed, in the absence of an explicit and clearly defined contract; that in the absence of such contract the practice of the boiler-maker must be taken as the meaning of the value of the horse-power of a boiler.

The motion was lost.

Professor Hutton: I feel rather inclined to call for a rising vote on that question. I think the decision of the Chair was right with reference to the testimony of the ear. But I wonder if it represents the sentiments of the Society? If I may, I would like to call for a rising vote.

A rising vote being taken the motion was declared to be lost.

Mr. Oberlin Smith: I move that the Society adopt the following resolution:

Resolved, That the thanks of the American Society of Mechanical Engineers are due and are hereby tendered to the citizens of Philadelphia for the elegant reception which, through their Committee, Messrs. George B. Roberts, A. J. Drexel, George W. Childs, George H. Boker, Dr. William Pepper, and Professor Fairman Rogers, was given them at the Academy of Fine Arts; and, that while they regard the same as a high personal honor, they prize it, also, as a mark of the esteem in which their profession is held in a city owing so much of its well-earned fame to its scientists, its engineers, and its manufacturers.

Agreed to.

Mr. Woodbury: I have a resolution which I wish to offer, and to move its adoption.

Resolved, That this Society tenders its thanks to the Franklin Institute for the use of its Hall; deeming it an honor to hold its sessions in a place of such importance, where engineering first became a recognized and honored profession in this country. Also that the members of this Society desire to express their obligations to the Trustees and Officers of that Institution for the courtesies received at their hands.

Agreed to.

MR. BARR: I beg to offer the following resolution:

Resolved, That to the various industrial establishments of Philadelphia, to whose open doors we have been so cordially invited, we have our thanks to offer, mingled with regrets that want of time prevented us from a general acceptance of the same. To the gentlemen connected with the few establishments to which time permitted us to make a brief visit, including as it does the firm of William Cramp & Son, John Roach & Son, the Baldwin Locomotive Works, William Sellers & Co., the Whitney Car Wheel Works, William Bement & Son, the Southwark Foundry & Machine Company, Ostheimer Bros., and others; and also to Commodore Pierce Crosby, of the U. S. Navy, the Trenton Iron Company of Trenton, the Betts Machine Company of Wilmington, Riehle Brothers of Philadelphia, and others who gave us special invitations to visit their works, we desire to return sincere thanks for the attentions shown us.

Agreed to.

PROFESSOR HUTTON: I feel a little modest, Mr. President, in rising to this motion.

WHEREAS, the preparations for our enjoyment and for the success of this Philadelphia meeting, have entailed a great deal of labor on the part of our Committees on Regular Meetings, on Rooms and Conversazione, and on the Joint and Social Committees;

AND WHEREAS, it seems only just and kind that the Society should recognize the work which has been so crowned with success, and that the members generally should express their appreciation of it;

Be it Resolved, That the Society tender its sincere thanks to the members of the above committees, for the efficient and gratifying way in which their difficult duties have been discharged in the preparations for this meeting, and during its sessions.

Agreed to.

MR. RAE: I offer this resolution:

Resolved, That the thanks of this Society are eminently due to the Engineers' Society of Philadelphia for its courtesy, hospitality, and great helpfulness on the occasion of our spring meeting, which have contributed in so important a degree to its great success.

Agreed to.

MR. WOLFF: I offer the following resolution:

Resolved, That the Secretary be directed to send copies of the foregoing resolutions to the various persons and firms from whom the Society has received attention.

Agreed to.

THE PRESIDENT: We have offered a paper by Mr. A. Faber du Faur, entitled "Expansion of Steam and Water without Transfer of Heat."

Mr. Wolff then read the paper.

Mr. Oberlin Smith read a paper entitled "The Positions of Views upon Mechanical Drawings."

The President: The next paper is by Professor Webb, on "Belting to connect Shafts which neither Intersect nor are Parallel."

Mr. Webb asked permission to dispense with the reading of the paper in full, and to present the subject orally. He then proceeded:

The point to be discussed is the proper position of two pulleys, upon shafts, which neither intersect nor are parallel, when the former are to be connected by a twist-belt.

The general law governing all cases of belting, when the pulleys are not grooved, is familiar to you all. For convenience let us call the points Z and Z′, where the belt runs off the pulleys, "points of departure," and the line ZZ′ the "departure connective," and let us understand by the "belt-plane" of a pulley, the plane perpendicular to its axis, in which the belt runs; then we may thus state the law, which is evidently true for flat belts: each point of departure must lie in the belt-plane of the other pulley." We will also speak supposing the shafting to be horizontal.

When the shafts are at right angles with each other, the ordinary method of setting the pulleys is correct. They must be so placed, that a plumb-line shall be tangent to both their surfaces, but when the shafts form an acute angle the law is especially inapplicable, and this method of setting is incorrect.

Here a model illustrating the subject was shown, of which the following figure is a perspective view. It consists of a suitable frame, supporting the cylindrical rollers, with their axes horizontal. The lower roller is turned by a crank, and drives the upper one by a belt, which latter, by means of a thumb-screw and a suitable joint in the frame, can be revolved about a vertical axis, and thus placed at any angle with the lower roller.

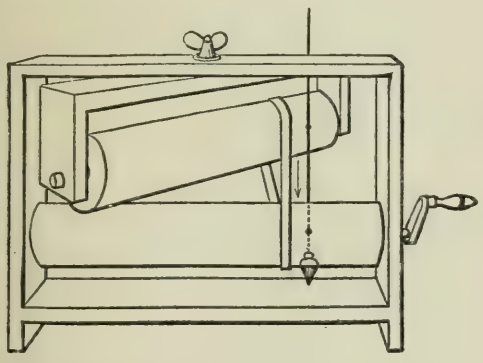
By placing the rollers at an angle of 45°, and a plumb-line tangent at once to both rollers, the incorrectness of the usual method of setting was made evident.

Two ordinary forms of models made in accordance with the old theory were here sketched upon the blackboard. The one

consisted of a drawing on cardboard with a hinge in the middle. Two circles were drawn, one on either leaf, with lines to represent an open belt connecting them Each circle was tangent to the hinge, and the direction indicated for the belt was such, that the points of tangency were very near the points of departure, and the hinge almost the departure connective. The other, simply two actual pulleys, so mounted that one could be revolved about their common tangent as an exis, while the pulleys were in motion, and without throwing the belt off.

The improved form of model substitutes for the pulleys rollers with no coning, and allows the belt to find its exact place on them.

The speaker then alluded to certain incomplete and incorrect



statements in standard textbooks, and proceeded to show, that the departure connective is not in general a common tangent; also that it is not the intersection of the planes of the pulleys.

These points were illustrated on the model, and the latter was explained as dependent on the friction between the belt and pulley. It was also shown that two belts having different coefficients of friction ran in different positions on the rollers.

Under the latter head it was shown that, before reaching the point of departure, the belt commenced to slip to one side, approaching therefore this point in a curve, which, by developing the surface of the roller, was found to be, when thus developed, a common catenary, whose parameter depended on the radius of the roller, and the coefficient of friction between the belt and the pulley. The speaker then concluded by giving

the descriptive geometrical method of finding the proper position of the pulleys upon these shafts, and with some statements in regard to practical cases.

Mr. See read a paper, on "Built-up Work in Engine Construction."

A paper entitled "A Note on the Action of a Sample of Mineral Wool, used as a Non-conductor around Steam-pipes," was read by Professor Hutton.

Mr. Nagle read a paper entitled "Feed-Water Heater Performance."

Mr Auchincloss read a paper describing "A Centre of Gravity Machine."

The President: We shall be compelled to pass several papers. We have a gentleman with us who has taken the trouble to come a long way with facts that will be of some value to us, and whom, I presume, the members would like to hear. The gentleman is a candidate for membership, and is not a member, and it will require general consent to allow him to present his material. If there is no objection I will call upon him.

The paper which Professor Lanza has been asked to read, as a guest of the Society, contains the results of experiments which would very properly have come into the discussion this afternoon,—"The Strength of Wood Columns as determined at the Watertown Arsenal."

Professor Lanza: I wish to express my thanks to you, and especially to your honored President, for the privilege I have had of attending this meeting and listening to the interesting papers which have been presented. I also must express my acknowledgment for the privilege of presenting to you the paper which I have prepared in regard to the strength of wood columns.

Professor Lanza then read his paper. No discussion ensued.

The President: As I said, there are several papers that can only be read by title. One of them is by Professor Robinson, on "The Strength of Members of Wrought Iron and Steel Bridges;" one is by Mr. Johnson, on "The Fly Wheel," and one by Mr. Sperry, entitled "Corrosion of the Propeller Shaft of the Steamship City of New York."

These will be printed in the Transactions, and published in some cases elsewhere. I have here an interesting letter, which

we will not stop to read, relating to the cause of the failure of the Pemberton Mills. If there is no objection the Publication Committee will be allowed to append it to Mr. Woodbury's paper.

NEW BEDFORD, MASS., April 13th, 1882.

MR. C. J. H. WOODBURY,
No. 131 Devonshire Street, Boston, Mass.

DEAR SIR: I fully concur with your views expressed in regard to mill-vibration.* When mills can be constructed of one or two floors, all the disturbances from oscillation or vibrations can be entirely avoided, and I am satisfied will give superior results during the existence of such mills, as compared with those where these things have not received any attention. When new enterprises are undertaken they are usually entered upon in great haste, and cheapness of construction is the great desideratum, without regard to its ultimate consequences. Durability, the absence of repairs, and the continued running of the machinery, are not given that consideration they should have, and many will have required a rearrangement, and a renewal of machinery, long before the time when it should occur. I was so fully impressed with the importance of guarding against the deleterious effects of oscillation and vibration to the building and machinery that, in the construction of the mill for the Wamsutta Company, of this city, I gave the most thorough attention to the matter, and which I think contributes much towards their success. In January, 1860, at the time the Pemberton Mill fell, I was engaged by your company to go to Lawrence to make a critical examination of the ruins, and spent two days there in doing so. The investigation fully convinced me the fall of the mill was occasioned by the vibration caused by the running of the shafting with imperfectly balanced pulleys on it, and machinery acting on the uneven bearings of the rough castings of the columns on their supports, and the pintles which were between them to form a continuous iron bearing from column to column, from basement to roof. The shaft and ornamentations about the capital were faulty, as they allowed thin places to occur in casting them by a very slight misadjustment of the cores (in some cases there were places in them not over $\frac{1}{16}$ inch thick), and rendered them unfit to support the great weight they had to sustain, while subjected to the hammering process of the vibrations of the floor-timbers, and floors between the supports, during the time the mills were running.

At this time (January, 1860) I was designing and sketching the plans for the Wamsutta Mills, No. 3, and this accident turned my attention more than ever before to the subject of the article you have sent to me, and suggested important changes in my plans.

While at Lawrence examining the ruins of the Pemberton Mills, I made sketches of the columns, pintles, floor-timber, floors, etc., and took the dimensions. I attribute the durability of the machinery in the Wamsutta Mill, No. 1, built in 1847, and Mill No. 2, in 1853, to be due to the extreme care used in the construction of the mill and machinery.

THOMAS BENNETT, JR.

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* Mr. Woodbury's paper having been already published, the letter referred to by the President, as above, is inserted here. (ED.)

PROFESSOR HUTTON: Before the adjournment, I would ask what is the understanding of the Society in reference to the obtaining of discussions of papers by members not present?

THE PRESIDENT: The discussions of those papers are sent with the papers to the members.

PROFESSOR HUTTON: Is it lawful under our rules for an expert member not the author of a paper read, and who was absent during its reading, to introduce observations of his own into the printed discussions, such as he would have made if he were able to be present?

THE PRESIDENT: There has been no precedent in the matter. I should say it would be a matter for the Publication Committee to decide unless objection was offered. It is done in other societies, and I presume there is no objection to it. As it stands now, it is with the Publication Committee. They have everything in their hands in regard to the publication of papers.

On motion the meeting then adjourned.

PAPERS

OF THE

PHILADELPHIA MEETING, 1882.

LVIII.

IN MEMORIAM.

Alexander Lyman Holley, Late Vice-President American Society Mechanical Engineers.

Obiit January 29, 1882.

Introductory.

The President: I feel that I have a peculiar right to speak in this place of the friend and colleague who has left us, to speak of him who was one of the most active among the founders of our Society, and of the man who was the ablest of his generation in our profession. As your presiding officer I stand in the place that he should have occupied, holding the position which he would probably have held had he not himself chosen otherwise, deferring an honor which he hoped, and of right may have anticipated, would be tendered him a little later, when, with improved health, he expected to pass an unbroken year among us.

The brotherly feeling that always unites men who have been taught within the same academic walls came to unite us a quarter of a century ago when we became alumni of "Old Brown." A mutual trust and confidence, such as rarely bind men seeing as little of each other as we did during the succeeding years, came to us, despite infrequent meetings, while the last few years had brought so many opportunities of intercourse that our friendship was cemented with a firmness and closeness of union that is still more rarely experienced among business men. Common tastes and closely related professional pursuits, similar interests, and pleasant memories of much that was common to our earlier manhood, led to a friendship of which the remembrance will never cease to yield sad pleasure to the survivor.

Mr. Holley was one of those who signed the call for the meeting for the formation of the American Society of Mechanical Engineers; he was the principal author of our by-laws and rules, and the leading spirit in the organization of the Society. He was a member of the Nominating Committee, and resigned

in order to oblige his colleagues by accepting a nomination as Vice-President, while positively declining nomination as the first President. He was one of those among the officers of our Society who were always present at the business meetings of the Council, and at all regular meetings, and who never allowed even important private business to interfere with the business of the Society.

No member was more thoughtful in regard to its interests, more prolific of plans for the promotion of its welfare, or more active and earnest in enlisting others in its support, and in bringing the leaders of the profession into our ranks. Mr. Holley was among the foremost in the movement to resuscitate the United States Board to test metals, and to reorganize the great scheme of investigation planned so carefully by that body, but hardly more than planned before the demise of the Board. He was the most active of our members in the organization of the plan for a gathering of European members of the several branches of the profession to meet our own representative men in convention in the United States, and to inspect, under the guidance of our committees, the public works and private enterprises of this country. This thought of a community of work, of pleasures, and of all interests, that should bring into contact all branches of the profession, and all members of our great guild, is illustrative of the breadth of his intellect no less than of his greatness of heart; and these qualities always became prominent in discussing those still weightier matters that had for us a common and more intense interest,—a rational system of education, and a general system of promotion of the useful arts and applied sciences by the united efforts of statesmen, men of science, and men of business,—matters that were always brought into view when, as was so often the case, "The Scientific Method of Advancement of Science" became the theme of our discussion.

Intellectually great, with a noble soul, and possessing the next essential, a powerful and vigorous yet graceful body, Mr. Holley was in all the days of his middle working life one of the finest illustrations of the type of man that Agassiz is said to have been. It was "the soul of a sage in the body of an athlete." But that soul has broken out from even such confinement, and that athletic frame yielded to the strain of the mightier soul temporarily confined within it; and to us is left

only the hope of a future renewal of intercourse and the remembrance of the past.

Our friend Holley was an honest and an earnest man. But such a man is not always the most useful man either to the world, to his fellows, or to himself. The honest, earnest man, who, in the excess of his zeal, deceives himself, is often the most dangerous of characters. The greater his intelligence the more dangerous the man. The greatest crimes that the world has known have been committed by conscientious, zealous men. Such men must possess a better judgment and a greater power of self-control than their comrades if they are to live useful, happy and successful lives.

Holley was an honest, earnest, intellectually great man, possessing that rare and sterling judgment, and having more than a common share of that woman's intuitive appreciation of the right, which is the best regulator of the earnest worker. The faith, the hope, the charity, the brightness, the earnestness, and the wholeness of heart that distinguished him, no less than his great mental powers and his professional standing helped to place him in the high position which he held among men. Shakespeare's admonition in that well-named play, "All's Well that Ends Well," was unneeded by our friend. To "love all, trust a few, do wrong to none," was, with him, second nature. His charity and his love covered all humanity; his faith in those about him, once given, was never withdrawn, except when, by some such bitter experience as we have all occasionally tasted, it was extinguished by betrayal.

Do wrong to none! His whole life was a mission of noblest beneficence, not only to his friends and his acquaintances, to those who loved, and to those who came to him necessitous, but to all nations, to the whole race contemporary with and succeeding him. He was of those few great and fortunate benefactors of mankind to whom we owe the highest material benefits brought to us by civilization.

Our committees are considering how, where and in what form, a suitable monument shall be erected to the memory of this most honored of our colleagues; whether to mount a bust of marble or of bronze in Central Park; to erect a statue at the capital of the United States, or to place some more modest but not less fitting and expressive memorial at his tomb. We may adopt either scheme; if we were to measure his deserts, they

would be beyond all these plans. It is of little consequence which is decided upon; his noblest monument is the memory which is implanted in the hearts of his friends, and in the memories of mankind. If these were not enough, we might erect in the midst of each of those great and wonderful industrial establishments built up so largely by his genius a tablet inscribed with his name, and the legend so familiar to the visitor to Sir Christopher Wren's tomb in St. Paul's, London:

"Si monumentum quæris; circumspice."

Let us hope that the time may come, and that soon, when a still nobler monument than any yet proposed may be built to perpetuate his fame.

The time must come, and that we will hope very soon, when a pressing want of this great country shall be supplied by the establishment of a complete system of thoroughly scientific practical education of the people for their work, a congeries of trade schools and of technical colleges, united into a thoroughly organized and well-administered whole. Such a system it seems now certain must be the work of private hands, and must be built up by the intelligent liberality of comparatively few wealthy and patriotic citizens. We have not yet statesmen in numbers, intelligence, and influence equal to the task of securing a governmental system of education such as has done so much for Germany and France. But the work is begun, and when it has so far progressed that the grand central, crowning, and directing member of the organization, a great University of the Arts and Sciences, shall have been found and endowed by some noble modern Vaucanson, or Worcester, or citizen more kingly than Ptolemy of Alexandria,—some one, perhaps, of the beneficiaries of the comrade whom we mourn,—let us hope that its most important department may be known as the Holley Memorial School of the Arts and Sciences of Engineering.

If other inscription is needed upon any tablet that may be erected, or upon the pedestal of the monument that shall be raised to the memory of this great man, this worthy successor in fame to the greatest of the inventors of the steam-engine, we may write with fitness and justice a paraphrase of that splendid tribute which may be read on the base of Chantrey's statue of Watt in Westminster Abbey:

Not to perpetuate a Name
which must endure while the peaceful Arts flourish,
but to show
that Mankind have learnt to honor those who best deserve their
Gratitude,
those among the People of the United States and of Europe
who love, honor and cherish his Memory have united
to raise this Monument to
ALEXANDER LYMAN HOLLEY,
who, directing the Force of an original Genius, early exercised
in Philosophic Research,
to the development of the modern Processes of Steel Manufacture,
enlarged the Resources of his Country, increased the Powers of Man, and
rose to an eminent Place
among the most illustrious Followers of Science, and the real
Benefactors of the World.

It is of this man that I am desired, that I myself desire, most earnestly to speak in fitting terms. But I am unable to do so. I have gone to my desk many times during these last sad weeks with the intention of putting on paper words properly expressive of the feelings that are awakened by the thought of our loss. But the words would not fit the thought, and after repeated trials I gave up the attempt. But one evening as I sat at my window, saddened and disheartened, I saw Sirius, that most beautiful and bright of all the stars, rising through the gray mists of the east, his sapphire rays quivering with varying refraction, steadily sweeping upward into the clearer space above, and finally shining out of the invisible dome with the brilliancy of a thousand diamonds, only made the brighter by contrast with the thousands of orbs of lesser magnificence which besprinkled the whole celestial vault.

I watched the progress of that glorious star, from hour to hour, as it so slowly, so steadily, so quietly rose towards the zenith, "ohne hast, ohne rast." After a time a thin cloud barely touched, without concealing, its light, and presently it shone free and clear again, and once more swung magnificently upward. Again, a broader and a thicker veil passed before it, dimming its lustre, and bringing upon me a startling fear lest the beautiful star should disappear forever from view. And even when it reappeared the apprehension remained with me and dimmed the pleasure that its recovered beauty should have given. How soon must a deep and impenetrable shade

conceal it forever. The star still rose, still bright, still beautiful, still wonderful in contrast with the galaxy about it, shining down upon the world with almost, if not quite, all its earlier splendor, blessing the world with light gathered in space away beyond the reach or ken of human minds, and impressing me with a feeling of strength, majesty, invincibleness, such as can only be realized in the presence of the most noble and incomprehensible of all creations.

At last, when nearing the zenith, when in the very height of its glory and beauty, those blue rays quivered again, struggling through the cloudy veil for a little time, flashed through a rift in the black, and disappeared. A shock came to my heart; a sense of desertion, of loneliness, and of grief beyond remedy. Gone forever! But a second thought brought relief. That great and glorious star is still there! It is but a veil of mist, impenetrable to vision, but hardly tangible, that has come between us. Another day will pass and all its magnificence and all its beauty shall again be ours to enjoy.

Another thought brought greater relief: A friend passes from our sight when at the zenith of his fame, in the prime of his manhood, in the height of his usefulness. But why mourn, and why seek to express the selfish sentiments of grief? He still lives. His is still the glory and the splendor of a great soul. Let the tongue be silent! His is the story of the star.

And yet, after all, to many of us who have long known this eminent man, who have found in him a valuable acquaintance, the pleasantest of companions, and the truest and kindest of friends, who, ourselves no orators and feeble even in the every-day use of language, nevertheless feel "more than tongue can tell," or yet "heart can hold in silence;" to many of us it is an unspeakable pleasure to be able to intrust our duty to a representative of ourselves and of the Society, who can, and who will gladly, say what we would say had we the power. For this we gladly turn to one who can give suitable expression to the grief which weighs upon us while we contemplate our loss, and while, nevertheless, we are conscious that our utterances should rather take the form of a song of victory for this immortal, and of congratulation that our friend who has now "passed over," has won so gloriously the peace, and the love, and the happiness of the better life, to which we may hope he may, in due time, welcome all who are left bereaved.

I have the honor to introduce to the Society the eulogist chosen by our committee to express for us all a common grief, common recollections, and a common hope. I present Mr. James C. Bayles, member of the Society.

LIX.

A TRIBUTE TO ALEXANDER LYMAN HOLLEY.

BY JAMES C. BAYLES, NEW YORK CITY.

Prepared at the request of the Committee on the proposed Holley Memorial.

Mr. President and Gentlemen of the American Society of Mechanical Engineers :

I have been asked on behalf and as a member of the Memorial Committee appointed by our Council, to formally express our deep sense of professional loss and personal bereavement in the death of our honored vice-president and dear friend, Alexander L. Holley. I have accepted this sad duty with satisfaction and with reluctance ; with satisfaction, because he was my friend through years of pleasant and, at times, intimate intercourse ; with reluctance, because I know that nothing I can say will give fitting expression to the sorrow we feel, each in his own way. Even the language of exuberant eulogy, could I command it, would seem out of place in this our lodge of sorrow, and inappropriate because none valued less than he mere phrases and declamation.

But how can we speak of Holley without eulogy ? He was at once so great a man and so dear a friend ; we knew him so intimately and loved him so well, that we, at least, cannot speak of him as of others who die crowned with honors gained in spheres of usefulness different from our own. He was one of ourselves, but now that he is gone we recognize as never before his immeasurable worth. I do not mean that he was not appreciated and understood by those of us who knew him best. We ever rated him far above his own modest estimate of himself, and involuntarily paid him the homage of an honor he never courted. But still he was *our* Holley, and now that he has vanished we stand like Gideon beside the wine-press,

when, gazing at vacancy, he knew to whom he had offered the meat and broth of his commonplace daily life. We realize now as never before that in his high sphere of special usefulness, Holley was one of the greatest engineers of his time, and that a generation hence the student of science who scans the metallurgical and engineering literature of this century, will see better than we do now the impress of his name on the corner-stones of more than one of the great industries of the future.

I speak to many who in Holley's death have suffered personal bereavement. To each of us the sad news came fraught with the dread significance of irreparable loss. To each it meant the severance of ties far stronger than we had realized until a pang in the heart revealed the truth. To each it meant a sorrow keen or dull according to the intimacy with which we had known him. Each of us has some legacy of personal reminiscence which, though better worth remembering than telling, is none the less a precious possession—precious if only the echo of his gentle, kindly voice, or the recollection of his earnest face beaming with a light which illuminated all about him. I count it as one of the most striking evidences of Holley's greatness and goodness that we remember him with an unconscious exaggeration of personal admiration. Who has yet heard even calm and impartial comment on his work and worth? When or where is he yet mentioned save with tremulous voice? Who recalls aught but good of Holley, or names him without such tribute of praise as few men merit while living or receive when dead?

In what is meant to be merely a tribute to Holley's memory, it will not be expected that I shall attempt to name or value the results of his varied, conscientious, and skilful professional work. With such knowledge of the subject as I possess, I can at most sketch freely and in outline the incidents of his phenomenal career. Had we time to look more closely we should see that the genius we so greatly wonder at meant simply tireless industry; that he moved upward step by step, by natural and regular development; that the results he accomplished were worked out by close study and clear reasoning. Luck and chance were not factors in the equation of his success. What he did he first knew; what he knew he first learned. There was no happy accident to mark the turning-point in his professional career. His inventions and improve-

ments were but the means by which he sought the attainment of ends kept steadily in view. Thoroughness characterized his habits of thought and of work, and those who knew him best, best knew how carefully he prepared himself for whatever he had to do. In this, probably more than in anything else, we find the secret of his uniform success in all the undertakings and duties of his brilliant career.

It detracts nothing from our estimate of his attainments to know that Alexander L. Holley began life under auspices peculiarly favorable. The child of exceptional parents, and born into a happy and virtuous New England home, the influences surrounding his early life were probably all which could be desired. He was a scion of the true American aristocracy,—an aristocracy of intellectual and moral worth. Knowing neither poverty nor riches, he felt the inspiration of necessary self-dependence without the discouragements and limitations of want. Quick to learn, he completed his studies at school in 1853, choosing the scientific course at Brown University in preference to the classical course at Yale, for which he had been prepared. He was then twenty-one years of age. At once we find him seeking the knowledge which can only be gained in practical work, and without which technical training has so limited a value. He went direct from the school into the large locomotive works at Providence, and for about a year ran a locomotive on the Stonington road. Years after, as President of the American Institute of Mining Engineers, we catch a suggestion of his fruitful experience in this modest capacity, in the striking passage in his address on "The Inadequate Union of Engineering Science and Art," in which he thus describes the relation of the driver to his engine: "The thoughtful locomotive driver is clothed upon, not with the mere machinery of a larger organism, but with all the attributes except volition of a power superior to his own. Every faculty is stimulated, and every sense exalted. An unusual sound amid the roaring exhaust and the clattering wheels, tells him instantly the place and degree of danger as would a pain in his own flesh. The consciousness of a certain jarring on the foot-plate, a chattering of a steam-valve, a halt in the exhaust, a peculiar smell of burning, a sudden pounding of the piston, an ominous wheeze of the blast, a hissing of a water-gauge, warning him respectively of a broken

spring-hanger, a cutting valve, a slipped eccentric, a hot journal, the priming of the boiler, high water, low water, or failing steam; these sensations, as it were, of his outer body, become so intermingled with the sensations of his inner body, that this wheeled and fire-feeding man feels rather than perceives the varying stresses upon his mighty organism."

Thus, unconsciously perhaps, Holley tells us how he carried his responsibilities in all the details of his professional work. It was not perfunctory service for wages or for profit, but a living experience, subjecting mind and body to constant tension. He had put something of himself into every member of the Bessemer plant. The throb of its machinery kept time to his own heart-beats, and he felt, as well as perceived, all the stresses upon the mighty organism with which his life was so closely identified.

At the outset of his professional career Holley began to write for publication. With an unselfish love of truth, he could not conceal or save for his own benefit the fruits of his study and experience. At twenty-three we find him a regular contributor to the technical press, especially to Colburn's *Railway Advocate*. About this time, I am told, there came a marked change in Holley's literary style. His earlier compositions, though enriched by occasional evidences of unconscious genius, were florid and sophomoric to a degree which cannot fail to excite a smile. At once he changed to the simple, earnest style which gave his literary talent the brilliancy of a cut and polished diamond. For this change Holley was no doubt indebted in a great degree to his friend and coworker, Zerah Colburn, and we can imagine what delight those wonderful young men must have felt in an association so fruitful of mutual benefit. Doubtless Holley owed much to Colburn. Without the aid of such a collaborator he would have made his way to substantial greatness; with it the road was shorter and smoother. But journalism, under whatever guidance or in whatever companionship, is an excellent school, and one in which Holley learned much that better prepared him for his life work. At twenty-four we find him proprietor and editor of the *Railway Advocate*, which, founded too early and without an appreciative constituency, suspended during the crisis of 1857. This release from serious and unprofitable responsibilities gave Holley a chance to go abroad for study.

At twenty-six we find him publishing with Colburn, as their joint production, a work on European Railways,* which had an immediate and important influence on American railroad construction and operation. At the age of twenty-nine we find him again started in what gave promise of a brilliant journalistic career. He went abroad as correspondent of the New York *Times*, and the scrap-books in which he preserved his writings are, I am told by Dr. Raymond, who now has them for examination, a mine of wealth from which might be compiled a brilliant and memorable volume. Of the value of his work as a contributor to the newspaper press we can have but little knowledge. That it was potent in stimulating invention and improvement we may be sure. Such work is often valued too lightly. It seems to possess but a transient interest, and to be pushed aside, almost before the ink is dry, by the fresh attractions of the next day's current literature; but every valuable article finds somewhere readers to whom it is worth more than a library of books. The writer for the newspaper press may often feel discouraged by the thought that what costs him so much is so soon forgotten, but every article which is worth remembering is remembered. Like the poet's arrows shot into the air and falling he knows not where, the work of the able and conscientious newspaper contributor exercises an influence he little knows. At twenty-eight, while still a journalist, we find Holley the author of a work on railway practice,† which at once became standard. When we remember that the materials for this treatise were collected at a time when he seemed wholly engrossed in newspaper work, we can but wonder at his extraordinary industry. At thirty, we find him

* The Permanent Way and Coal-burning Locomotives of European Railways, with a Comparison of the Working Economy of European and American Lines, and the Principles upon which Improvement must Proceed. By Zerah Colburn and Alexander L. Holley, with 51 engraved plates by J. Bien. New York. Holley & Colburn, 1858, 4to.

† American and European Railway Practice in the Economical Generation of Steam, including the Materials and Construction of Coal-burning Boilers, Combustion, the Variable Blasts, Vaporization, Circulation, Superheating, Supplying and Heating Feed-water, etc., and the Adaptation of Wood and Coke-burning Engines to Coal-burning; and in Permanent Way, including Road-bed, Sleepers, Rails, Joint Fastenings, Street Railways, etc., etc. By Alexander L. Holley, B.P., with 77 plates, engraved by J. Bien. New York, D. Van Nostrand, 1st edition, 1860; London, Sampson Low, Son & Co., 4to. 1st edition, 1867, 2d edition, 1867.

going abroad for Edwin A. Stevens to study ordnance and armor; and at thirty-three he published a work on these subjects* which was alone sufficient to give him a recognized position in the front ranks of engineers. Meanwhile he had secured for American capitalists the Bessemer patents, and built at Troy experimental works. He had thus reached professional eminence at an age when most men are but laying the foundations of a career. In this department of metallurgical engineering his extraordinary talent found full opportunity for its greatest achievements. How much he did to create the Bessemer steel industry in this country and make our average practice superior to the best foreign practice, has been ably and frankly told by Mr. Robert W. Hunt, of Troy, in a paper before the American Institute of Mining Engineers.† When we remember in how short a time this industry has attained its present extent and prosperity, and with what giant strides it has moved forward to a point at which its statistics overshadow those of Great Britain, we cannot fail to find interesting the story of how this was brought about, chiefly by Holley's persistent industry and close study of details. Fully impressed with the possibilities of the Bessemer process as he had witnessed its workings in England, he inspired others with his own enthusiasm, and under his direction the original plant of the Albany and Rensselaer works at Troy was built. Previous experiments with the pneumatic process as patented by William Kelly, had been made at Wyandotte, in which Mr. W. F. Durfee, of our membership, took a prominent part, and he and his associates are certainly entitled to share with Holley the credit of the first great improvement in the process, the substitution of the cupola for the reverberatory furnace for melting the iron to be charged into the converter. Mr. Durfee's failure to make this improvement successful was due to the small size of his cupola, the distance the iron had to be

* A Treatise on Ordnance and Armor, embracing Descriptions, Discussions, and Professional Opinions, concerning the Material, Fabrication, Requirements, Capabilities and Endurance of European and American Guns for Naval, Seacoast and Iron-clad Warfare, and their Rifling, Projectiles and Breech-loading. Also, Results of Experiments against Armor, from Official Records; with an Appendix, referring to Gun-cotton, Hooped Guns, etc., etc. By Alexander L. Holley, B.P., with 493 illustrations. New York, D. Van Nostrand, 1865; London, Trubner & Co., 1865, octavo.

† Transactions, A. I. M. E., vol. v. pp. 210–216.

moved in the ladle, and the fact that, being low in silicon, it would not generate heat enough to produce the proper reactions when blown in the converter. Holley's success with the cupola was due to better and more convenient arrangements. Though not the first to make steel by the pneumatic process in this country, the Troy works were the first to approximate a commercial success. Early in the history of this industry Holley seems to have concluded that the best foreign practice was merely a starting-point for an ingenious American engineer to work from. His talent was eminently practical, and in his judgment nothing was successful which did not give satisfactory commercial results. The task he had undertaken was a great one. Not only was the process to be adapted to the conditions here existing, but the popular prejudice against the product must be overcome by maintaining a standard of quality which should disarm criticism and command the confidence of consumers. Having made successful the melting in a cupola of the iron to be converted, he began to experiment with American irons, with enough success to encourage efforts on the part of furnace managers to provide a grade of pig suited to the process. The Troy plant was increased by the erection of a 5-ton converter, and Holley then assumed charge of the erection of the plant of the Pennsylvania Steel Company at Harrisburg, for which he had previously designed the machinery. In 1868 he returned to the management of the Troy works, which he partially remodelled in the light of experience gained at Harrisburg, and the improved plant made its first blow in 1870. His next important improvement was the substitution of a 30-inch 3-high blooming train with lifting tables, for the cogging hammer, in the reduction of ingots. George Fritz, a great mechanic, between whom and Holley existed an almost fraternal love, subsequently devised an apparatus which displaced Holley's improvement, and carried economy a step farther. Standing admittedly at the head of this branch of the profession, Holley was called upon to build or design one after another of the Bessemer works, or to assist with his advice and experience the engineers immediately in charge.

Mr. Hunt, in the paper before mentioned, thus summarizes the result of Holley's work up to the year 1877:

"The result of his thought gave us the present accepted

type of American Bessemer plant. He did away with the English deep pit, and raised the vessels so as to get working space under them on the ground floor; he substituted top-supported hydraulic cranes for the more expensive counter-weighted English ones, and put three ingot cranes around the pit instead of two, and thereby obtained greater area of power; he changed the location of the vessel as related to the pit and melting-house; he modified the ladle crane, and worked all the cranes and vessels from a single point; he substituted cupolas for reverberatory furnaces; and last, but by no means least, introduced the intermediate or accumulating ladle, which is placed on scales, and thus insures accuracy of operation by rendering possible the weighing of each charge of melted iron before pouring it into the converter. These points cover the radical features of his innovations. After building such a plant he began to meet the difficulties of details in manufacture, among the most serious of which was the short duration of the vessel bottoms, and the time required to cool off the vessels to a point at which it was possible for workmen to enter and make new bottoms. After many experiments the result was the Holley vessel bottom, which either in its form as patented, or in a modification of it as now used in all American works, has rendered possible, as much as any other one thing, the present immense production."

Of what he has done since this was written we can learn only by a search among his papers. In the position of Consulting Engineer of the Bessemer Association, he worked with tireless industry, but with probably less advantage to his reputation and fortune than had he worked in another capacity. His responsibilities were great, and although his work cannot be said to have been profitable to him in proportion to its value to those for whom it was performed, he was too conscientious to consider his own interests to the sacrifice of theirs. It was not until a manifestation of their feeling of absolute ownership stung Holley's proud and sensitive nature, that he sought to sever this connection by resigning his position. But they were in no mood to part with one on whom they had learned to depend so absolutely. He remained to the last trammelled by a professional engagement he could not resign and was loath to sever, but which gave him a vast opportunity for usefulness in the line of his best abilities.

Considered as an inventor, Holley had fewer claims to recognition than many men whose lives have been of very much less benefit to the world. His talent was more fruitful of immediate results than that of the restless discoverer who is always pushing into the wilderness of possibilities as yet untraversed by the beaten paths of human endeavor. Holley cannot, I think, be called an inventor. He made no great discoveries, and, so far as I can learn, every invention claimed by him had for its object the provision of better means of reaching an end previously aimed at or attained.

His first patent was taken out in 1859, when he was twenty-seven years old. It was for an improved railway chair, and describes a device to preserve the continuity of the track by brackets so attached to spliced pieces and tension plates that the weight of the train wheels on the rail should keep the splices tightly in their places without the aid of plates, nuts, keys, or rivets.

In the same year he took out a patent for a cut-off gear for steam engines, describing an apparatus in which a combination of the motion of an eccentric or its equivalent with the motion of a steam piston for moving a valve, effected a variable cut-off of the induction steam without interfering with a free exhaust.

Ten years passed before he again claimed protection as an inventor. In 1869 he patented a combination of crane, converter, and chimney, so placed relatively to each other that the crane could swing entirely around in its orbit over the converter without coming in contact with the chimney. One side of the converter was supported by a beam, in such a way as to permit a car to be run under it from one side ; and it was claimed that by the arrangement of oven, crane, car, and lift for removing the bottom of the converter, special advantages were gained over those pertaining to the arrangement previously employed. A guide and hand screw were provided in connection with the improved arrangement of parts, so that the ladle stopper could be readily adjusted.

Again in 1869, he patented a shield in connection with a Bessemer converter, for the protection of the workmen. A tuyere box is described in combination with the converter bottom, and the latter was so constructed as to admit of its introduction through the former.

In 1872 Holley patented the converter bottom which bears his name. The patent described a construction of notched bricks shaped so as to be set below and around the tuyeres, the spaces between being rammed with ganister; and to more readily dry the mass screw plugs were provided, which passed through the ganister and boxes.

In the same year he took out two patents relating to the casting of ingots. The first of these describes a mould so arranged as to fill from the bottom to any height desired; the second described suitable moulds, in connection with a solid flask containing suitable runners leading from one mould to another, and lined with a refractory metal to prevent a too rapid abstraction of heat from the molten steel.

In 1873 he patented a stopper for ingot moulds, supported at different points by elastic flanges or friction springs, and on the same date an ingot mould provided with an adjustable cast-iron stopper.

Towards the close of 1873 he obtained a patent on improved rolls, in which the middle roll was adjusted by two screws, one right and the other left-handed, passing through the bolster at either end and operated by worm gearing connected with the pulley above. Fore and catch plates were fastened to lugs on the bolster of the middle roll, and carried by these when the roll was adjusted. A stop on the bolster limited the height to which the metal was raised by the table.

Three years later he invented and patented a furnace construction, in the roof of which were spaces for air, water, or spray conduits for cooling the same.

In 1879 he patented a feeding device for rolling mills, in which the feed rollers were mounted on a special frame provided with suitable mechanism imparting a proper motion, and adapting the apparatus for feeding either long or short pieces. Another device consisted in a rocking frame attached to the housing. The feed-roller frame was carried by the rocking frame, and suitable mechanism is described to guide the pieces and impart a rotary motion to the feed rollers.

Two years later, in 1881—scarcely more than thirteen months ago—he patented a steam boiler furnace, in which the essential device consists of alternate ports, with a diaphragm so placed over them as to thoroughly mix the gases entering through the ports. The space below the diaphragm

constitutes the combustion-chamber in which the gases are burned.

One year and seven days ago * his last patent is dated, which describes the removable converter shell, of which I shall speak somewhat more fully later on.

This, I believe, is a brief record of Holley's work as an inventor of new and patentable devices. The list is not a long one, and the casual reader will not find therein much to sustain a claim to great originality or a talent for discovery. But when we remember what some of these improvements have done for one of the great industries of the country, and how they have helped to place us in the front rank as steel producers, we see that the world owes Holley more than it does many who anticipate industrial progress and stake out claims which succeeding generations may perhaps work with profit, but which when located lie outside the busy circle of the world's activities and industries. I regard Holley's mechanical talent as eminently practical and characteristically American. He ever sought "convenient means." To facilitate, to simplify, to save labor, to economize where economy was profitable,—these were the ends he strove for and attained. Bessemer probably has more claim to recognition as a great inventor than Holley; but if we compare the two men we see strikingly exemplified the difference between the inventor and the industrious engineer. Where Bessemer left the process which bears his name, Holley's work began. It was full of possibilities which Mr. Bessemer, distracted by a restless ambition to do something new in marine architecture and other lines of experiment, not always judiciously chosen, seems to have aided but little in realizing. Holley was content to be useful; the typical inventor leaves the question of utility for others to answer, and pushes on. It is as an engineer, rather than as an inventor, that Holley must be considered great; and not alone as an engineer, but as a teacher of the accomplished facts of scientific progress. He had a faculty for imparting to others the fruits of study, observation, and experience, which is given to but few men. Not only was he lucid and clear in his description, but even around the dry details of mechanical proportioning and construction he cast a glow

* April 26th, 1881.

of color, and truth when he presented it became poetic. How much his writings have enriched the engineering literature of the two continents, I do not need to tell you. Holley's life and work merit all the honor we can pay his memory, and his title to substantial greatness is beyond the reach of question or criticism.

There is something very pathetic to me in all of Holley's death-bed utterances, but especially in those which touched upon his work. "I should like," he said in effect, "to live ten or fifteen years longer to aid in realizing the possibilities of the open hearth process. This would have rounded and completed my professional career; but I am satisfied." To long for an opportunity of further usefulness was natural to one whose life had been so full of great achievements, but to speak of rounding and completing such a professional career seems like wishing to gild fine gold. Not so to Holley! Death to him meant simply leaving undone that for which he had made earnest preparation, and which he desired to do because he could do it best. Others will do good work, great work, but not his work.

> The unfinished window of Aladdin's tower,
> Unfinished must remain.

Holley's connection with the Society of Mechanical Engineers is a memory of which we may well be proud. Perhaps to him more than to any other member its success is due. His active interest in the project was in itself an assurance that it would realize the objects of its organization, and his name created confidence in all departments of the profession. Some of us, but probably not many, know what effort he made to secure a good attendance at the Hartford meeting, and how anxious he was that the dinner should be a complete and memorable success. He knew better than most of us the value of recreation as a preparation for the serious work of life, and long experience had taught him that to make the social features of our society meetings delightful was the surest way to make such meetings successful. In our dinners we have a perpetual memorial of Holley. On such occasions he enjoyed life at its best, and how much his presence added to our pleasure I do not need to say. Unfortunately, failing health deprived him of the opportunity of contributing liberally to our Transactions,

but had he been spared he would have aided materially in giving us a high place among the great technical societies of the world. I have lately re-read with pleasure and profit his address as chairman of the preliminary meeting in February, 1880, on "The Field of Mechanical Engineering," which is charming in its simple earnestness and brimming with valuable suggestions to officers and members.

We have also on our records the fullest, and, I believe, the first description of his last great improvement,* which is in a striking degree characteristic. Convinced from examination that the basic process was a chemical success, he also saw that it presented difficulties which threatened to make it useless in this country. Having brought the Bessemer practice up to the high perfection which it had attained in the working of the so-called acid process, he recognized the impracticability of restricting a steel plant in the United States to the comparatively small production which satisfied English engineers and capitalists. When Thomas was in this country he and Holley were at Troy together. Thomas was greatly interested in all he saw, and while in the converter-house he remarked that he "should like nothing better than to sit down on an ingot mould and watch the work all day." "If you want to find an ingot mould cool enough to sit on," replied Holley, "you will have to send to England for it." Holley's improvements had rendered impossible the delays which would have resulted from the frequent relining of converters, and to perfect the basic process he had hit upon the clever expedient of making the linings detachable, so that with very little delay a new lining could be substituted for one burned out, and the work go on, enabling our steel-makers to adopt the basic process, when it is to their interest to do so, without sacrifice of product. This was the crowning work of Holley's life, and to us he gave the paper which would have been welcomed by the greatest technical societies of the world.

It is much to be regretted that petty jealousies led to the decision to withhold from Holley the Bessemer medal, which he, more than any engineer, had earned; but he was too great a man to be made unhappy by the fact that he had excited in weaker minds feelings which found no place in his own great,

* "An Adaptation of Bessemer Plant to the Basic Process." Read at the Annual Meeting Soc. Mech. Eng., February, 1880.

loving heart. The consciousness that he merited the honor was worth more to him than to have had it grudgingly bestowed by those who knew, but dare not confess, that he towered high above those who sat in judgment on his claims to recognition. The love of his friends was always worth more to Holley than barren compliment, and he died without uttering a word to indicate that he had known a disappointment in life. Even in the detention of his stricken family, who were hurrying to his bedside, he saw a blessing for them which outweighed the satisfaction it would have given him to look once more upon those nearest and dearest to him; and among his last words was a message that he died without disappointment, knowing that it would be less a shock to them to find their worst fears realized, than it would be to find him unconscious and see him die without even a look of recognition or a word expressing the infinite tenderness of his love. One capable of such forgetfulness of self in the presence of the awful reality of death could look with equanimity on the petty annoyances which make weaker natures unhappy.

Of Holley's personal character, I can speak only as a friend and best describe him as he seemed to me. Perhaps I owe him more than I would care to tell. He won my confidence and regard years ago, when with nothing but youth and inexperience to commend me to his consideration, I sought his counsel and was freely admitted to his confidence. You can estimate better than I can describe the value of such a friend to one weighted with grave and anxious responsibilities, and impressed with a sense of the inadequacy of his preparation for the work devolving upon him. It is the experience of the journalist that truth is sometimes difficult of access. The statements made to him are often colored by a regard for real or supposed self-interest, and misrepresentation masquerades in the garb of frankness and confidence. But when I met Holley and sat with him for half an hour in confidence, I would have pinned my faith to his deliberate statement, otherwise unsupported, against the oaths of all the world. Holley was to me a revelation. Not only was he a man of whose sincerity no one could entertain a doubt, but he was one who dared to put confidence in the sincerity and honesty of others. It was as refreshing to talk with him as to pass from the gray shadows of a closed chamber into the full glow of sunshine,

from the chill of reserve and suspicion into the genial warmth of outspoken frankness. Others I have found honest and true, others have won my love by unselfish service, others have given me wise counsel and judicious advice. Their sincerity I have proved; Holley's sincerity needed no proof.

During the twelve years of an acquaintance which I shall always remember with pleasure, it was my privilege to learn by observation and experience the generous side of Holley's nature. Never have I known him too busy to see one who needed his assistance; never did he promise aid without rendering it. In our great metallurgical establishments are scores of young men who have reason to bless the memory of this unselfish friend, whose timely assistance opened the way to honorable professional success. With Holley there was nothing perfunctory in this service for others. It was his pleasure in a peculiar degree to confer benefit, and he was never so happy as when it was in his power to bring happiness to others.

Of the irresistible charm of Holley's conversation, of his sunny temperament, his brilliant wit, and his genial good-fellowship, I need not speak; but remembering all these I am moved to write on the tablets of memory as his epitaph, a paraphrase of the remark of the old farmer of Marshfield as he stood beside the bier of Webster: "This is a lonesome world and Holley dead."

Responses.

The President: I see among us a gentleman, who, although not a member of our Society, is a member of two of the great societies of Great Britain. I would like, if he is willing, to have him say a few words on this occasion—Mr. Fernie.

Mr. Fernie: *Mr. Chairman and Gentlemen:* Although not an intimate friend of Mr. Holley, yet I had the pleasure of meeting him in this city in 1876; and I know a good deal of his work, and I can bear high testimony, as an English engineer, to the very high appreciation we have in our country for his mechanical skill and genius. He commended himself to us in a great many ways, principally as a writer, as an inventor, and as a connecting link between English and American engineers. So, whenever Mr. Holley came to any of our meetings we looked upon him as your representative, and treated him ac-

cordingly. I assure you that there is a great blank in our societies in England caused by the death of Mr. Holley, and that we mourn his loss as much as you do, for we considered that he belonged to us as he belonged to you. There are a great many small minds in our country, as I dare say there are in yours, who do not look at men with the broad feelings and respect with which they ought, and who regard them in an envious sort of way; but the general feeling of the engineers of our country as regards Mr. Holley was a feeling of genuine respect.

After the eloquent words which have fallen from the last speaker, the most eloquent memorial tribute which I have ever heard, it will be improper for me to express more than my deep regret for the death of Mr. Holley, and to say that we mourn his loss as deeply as you do.

One word in regard to a subject that came before your Society this morning. In respect to a meeting of Mechanical Engineers of England and America, I may say that two years ago I tried to get up a party to come to the United States. At our annual meeting, Mr. Barlow, our President, mentioned in his address the pleasure which a visit to the United States had given him. He was present here at your great Exposition. And after he made that statement I thought it my duty, as having several times visited on this side, to try and get up a party to come across here and see your great works, and try to meet our professional brethren in America and have more fellow-feeling with them. But I found that a long time would be required for such a visit, and that considerable expense would attend it; and although I got Cook, the great excursionist, to arrange about a steamer for us, yet when we learned the length of time it would take, it was found impracticable to get up a party. I believe that is the great trouble with engineers coming to America. I wish we could shorten the road. I hope in a few years we will get it down to six or seven days, and at that time we hope to get a considerable number of English engineers over in America. We have a great many American engineers coming to England, but very few going from England to America. I wish there were more.

THE PRESIDENT: The road between England and America is being shortened very rapidly. The Alaska made her last passage in six days and twenty-three hours.

We have among us one of our old officers, who was also

President of the Institute of Mining Engineers. Can we hear from Mr. Coxe?

Mr. Coxe: I have been at many meetings of the Civil, Mining, and Mechanical Engineers at which our dear old friend Holley was present. This, gentlemen, is the first one I have attended since he has gone. As I look around and see so many who have been with us when Holley was here, I feel as if I could say nothing. Holley was a man who made us better. He made us stronger. He made us act like men and feel like men; and I do not believe that there is a man worthy of the name, who has had the honor and the privilege of being well acquainted with Alexander Lyman Holley, who has not found himself a better man. Of him we may well say: "It is better to have loved and lost, than never to have loved at all." I am not speaking of his great genius as an engineer; that is not necessary; he wrote his name as an engineer where none can efface it; but as a friend, as a man, as one who made engineering a profession. And I think to Alexander Lyman Holley the profession of engineering owes more to-day than to any other man who has lived on this side of the Atlantic. Those who were with him in the American Society of Civil Engineers know what he did for its advancement, and I who labored with him for so many years in the American Institute of Mining Engineers know what he did for that Society; and we all feel and must say if we speak the truth, that but for him it is very doubtful if this Society would have come into existence, at least for some time. I feel that I should be but repeating what is in all your hearts, were I to say anything in his praise; and I can only repeat that this is the saddest meeting that I have ever attended. I feel that I would like to go away, as I see his loved face before me there, and think that we are never again to meet upon this earth. I wish almost that I were not here. Gentlemen, let us all try to leave behind us a name like this,—*sans peur et sans reproche*,—the Chevalier Bayard of our profession. He did everything to advance and glorify engineering, and never anything to sully its fair fame.

The President: We have among us another gentleman, who has watched Mr. Holley's work with more intelligence, more power of comprehension, than most of us could have done, and one better qualified to speak of his works than any man among us. We would like to hear from Mr. Hunt.

MR. HUNT: *Mr. President and Fellow-Members:* I can hardly trust myself to speak of Holley. Yesterday I happened to be in the shops of the Corliss Steam Engine Company, and mentioned to one of the workmen there that I expected to-day to attend the memorial meeting of the Mechanical Engineers on the death of Alexander L. Holley. The man exclaimed: "What! our Holley?" And so it is, whether it is among the workingmen or among the cultivated engineers, it is to "our Holley" that we to-day seek to pay our tribute.

Sadness is rendered less painful when the privilege is given us of making expression of our grief: "Out of the fulness of the heart the mouth speaketh." Oh how full our hearts have been, and are, from the loss of our friend and fellow-member. In my reflections upon dear Holley's death, I have so many times thought of the death of his close friend, and one of our most cherished members, one who felt so much interest and filled such an active part in the organization and success of this Society,—Henry R. Worthington.

Many of you will remember that at our second meeting, the one held for the purpose of final organization, Holley was too ill to be present, and Mr. Worthington in his stead read the report of the Committee on Constitution and By-Laws. In a few weeks Holley, having partially recovered, sailed for Europe, where, later, he experienced the terrible sickness which so nearly ended his life. During this time, while his family and friends were anxiously awaiting each cablegram, several professional associates and myself had occasion to visit Mr. Worthington's office. We found him holding a message in his hands, and overwhelmed by grief. His feelings were so overpowering that speech was almost impossible. At last, in eloquent, heartfelt words, he pointed out to us his sorrow. Holley was dying!

What a beautiful tribute he paid to his character. Worthington himself, most genial of men, most pure, most talented, laid his garlands at the feet of one whom he loved for these same qualities. Would that I could to-day pay my tribute to Holley's memory by repeating Worthington's words.

How past all comprehension is fate! Worthington died; Holley came back to us apparently restored to health, and was himself the mourner at the tomb of his friend. And now both are gone. The world has lost much, and of the world this Society is among the heaviest sufferers.

Holley's character is best illustrated by the peculiar marks of affection and respect which have been paid to it since his death. Who would not live such a life? But few can. Such an intellect, such a simple, loving, all-embracing heart is seldom given. But while mourning his loss, we can all endeavor to prove ourselves worthy to have received his love, to have been of his friends.

Whether or no tablets of stone or monuments of brass are erected to his memory, the Memorial Session, at Washington, of the American Institute of Mining Engineers, this of our own Society held to-day, and the action of the American Society of Civil Engineers yet to come, are greater, better, sweeter tributes, tributes such as none but Holley could have called forth.

Nevertheless let us do more, let the three Societies meet in rearing an enduring physical tribute—one alike appropriate to his genius, his love of art, and the good done by him for his fellow-men. Let it stand as an example of the value of practical science, of practical work, and as a beacon to the young men of our country, of whose welfare, of whose guidance, of whose fortune his great heart was so full.

THE PRESIDENT: I see there is another gentleman with us, who is also a member of this and of the sister Societies, who has worked with Holley on the Boards of direction of those Societies, and has himself been President of the Mining Engineers, and is one of our most active and most valued members. Will Mr. Metcalf address the Society?

MR. METCALF: In 1874, I had the pleasure of first meeting the man we have to-day met here to honor. In 1874, it was my fortune one day, as I incidentally dropped into one of the machine shops of our city, to be directed to the pattern shop, and further into a little, dingy corner to find one of the employers. And there in this little dark corner of the place, I met a man who was introduced to me as Alexander L. Holley, and the bright face, and the sweet smile, and the clear intelligent, flashing blue eyes that were set on me that day, are just as clear in my mind at present as they were at that time, and that was my first meeting with Holley. Afterwards it was through his influence that I was induced to join the American Institute of Mining Engineers. It was partly through his influence that I became a member of the American Society of

Civil Engineers, and it was altogether through his influence that I became a member of this Society. To him I owe the great honor of having the nomination to the office of President of the American Institute of Mining Engineers, and when called upon to-day, Mr. President, to speak of Mr. Holley, I hardly know what to say. Of his career, of his professional work, many gentlemen here to-day know far more than I do; and I have simply jotted down a few remarks to add as a tribute to the character of Mr. Holley, which I hope will be deemed at least worthy to go upon the records of this meeting, which is intended, as I understand, simply to be a tribute to the memory of a man who was all love, honor, and respect.

We all know why we loved Mr. Holley,—simply because we could not help it. Not merely because he was sweet-tempered;—many a man has a sweet temper and is insipid. Not only because of his knowledge, for many a one is learned, and no one else is ever allowed to know it. Not because of his many-sided attainments, for many people acquire many things only to air their own vanity. Holley had sweet temper, profound knowledge, and a great variety of attainments, and he poured them out so lavishly, so persistently, and best of all so modestly, that he drew us all to him whether we would or not. But in what was Holley great? He was great in his far-seeing apprehension of the utility of things. He had the enthusiasm of a zealot, the courage of one convinced, and the energy of inspiration. He seized upon the great Bessemer process when capitalists were afraid, when old practices and ignorant prejudice derided it, and when a slumbering world had no idea of its own needs. He gave courage to capital, bent down ignorance and prejudice, and showed an astonished world what a poor world it was before. He was successful in probably the greatest of engineering feats, for his task was no wide chasm to be spanned, no great mountain to be pierced, no large river to be guided and controlled, nor a huge swamp to be filled up and made useful.

These are all great works, but their accomplishment depends mainly upon common-sense, and the knowledge and application of well-known and changeless laws of nature. Once completed they stand fulfilling their objects and requiring but little care for their preservation.

Holley went to the capitalists and said, "Give me your

money, and I will span the great chasm between now and to-morrow; I will blow to atoms the mountains of ignorance and prejudice; you shall float upon rivers of wealth; and old ways and old methods shall be completely swamped. I will take your dollars and convert them into buildings, and furnaces, and mills, and hammers; I will put all of these fair structures into the hands of the most ordinary men, and they shall do all they can to smash and tear them in pieces. They shall fail; I shall succeed, and you shall be rich." He did succeed, and why? How could this man, poet, artist, architect, lover of all that was beautiful, succeed in such a task? He did it because he was modest, and kept himself in the background. He pushed everyone but himself to the front, and the front rank bore him aloft on its shoulders, and he fulfilled his promises. The little streams of thousands, invested in his many contrivances, united into a great river of millions, and his patrons still gathered up the profits. And here is the great secret of his success. He never allowed his love of the beautiful to get the better of his sense of the useful: and he never allowed his ambition to overcome his faith to the trust reposed in him.

He was happy when he saw each new work completed and running successfully, but he was most happy when he could say, "They are working economically and making lots of money." All I have said seems as nothing, Mr. President, and I can think of no more fitting words to close than those of a friend whom I met the other day, who said: "I cannot tell you how I miss him."

THE PRESIDENT: We have with us a gentleman who has been in a certain way a co-worker with Mr. Holley, and who has helped him through a good many of his difficulties, and whom in turn he has helped very much. There was a sympathy between those two gentlemen, such as I am sure would justify me in calling for Mr. Charles T. Porter.

MR. PORTER: *Mr. President:* In coming here, I confess to you, sir, it is not the great engineer, it is not the man of strong purpose and heroic endeavor, it is not the foremost figure in the band of giants who have created the great steel industry of this country, neither is it the brilliant writer, nor the man of high and varied attainments, whom my memory most loves to dwell upon; oh, no! Alexander Lyman Holley was all this; but,

sir, he was a great deal more than this. That beaming countenance with speaking eyes, upon which it was such a joy to look, and which, to everyone who ever gazed upon it, it will ever be such a joy to remember, was the outward manifestation of a great soul, instinct with every feeling, that, in the appropriate words of another, can ennoble or can adorn our nature.

The opportunity for studying Mr. Holley's character, which I enjoyed for the past few years, enabled me to form an estimate of it which is more high than I can very well express. It seemed to me, it always has seemed to me, as if Mr. Holley combined in a wonderful degree, strength and elevation of character, with warm, loving sympathies and sensibilities. It seems to me, sir, as if it could be fairly said of our dear friend, that whatsoever things were honest, whatsoever things were just, whatsoever things were pure, whatsoever things were true, whatsoever things were lovely, that to all such things he was ever loyal. These were the things which called forth all the enthusiasm of his nature, and with which his every heart-beat throbbed in harmony. Such a character, Mr. President, as that of Mr. Holley, must leave an unusually marked impress upon the great number of his co-workers, by whom he was admired and loved; and it is a joyful thing to think that, as it ought, so it must, tend thus to perpetuate itself in ever-widening circles, however they may grow more faint, throwing its spell upon everyone who comes however remotely within the sphere of its influence. And so we can write his name among the names of those who not only have added to the material good of their fellow-men, who not only have contributed largely to the advancement of our civilization, but through whom men have been made better, have been made more just, have been made more generous, have been made more pure, have been made more loving.

THE PRESIDENT: I will next call upon Mr. Hoadley, of Lawrence.

MR. HOADLEY: *Mr. President and Gentlemen:* I received information from the committee having the commemoration in charge, that a few minutes would be accorded to me to speak of my regard for Mr. Holley, and I received this invitation with profound satisfaction, and have spent hours in pleasing melancholy, thinking over the associations that have taken place between us. When I consider how few and

how far between were the occasions when we met, and upon how slender a foundation of actual personal intercourse was based the strong and warm personal regard I have always entertained for Mr. Holley, I feel that it must be futile for me to attempt to account to you for the feeling I express, which might seem, therefore, extravagant; and that it would be entirely idle for me to dwell at any length upon his career, which is quite as well known to you all as to me.

Almost twenty-five years ago, when Mr. Holley was a very young man, I intrusted to him a delicate negotiation in England, when he was about to go to England with Mr. Colburn to prepare their joint work upon European railways and machinery. He performed this negotiation with great tact and delicacy, but with characteristic generosity he declined to receive any compensation, and could only be induced by considerable urging to accept a trifling remuneration for personal expenses. A few years later, in 1863, I met him in London. I was almost ready to go home, and Holley had arrived but a few days. He was seeking at that time to make arrangements with Mr. Bessemer for the manufacture of Bessemer steel in this country. With a perspicacity entirely characteristic of the man he had perceived the transcendent importance of this invention, which was almost unnoticed by the world, and before Mr. Bessemer had ever received a shilling of legitimate compensation for his invention. True, it was the year he had received a present from Sir John Brown of two thousand dollars. Mr. Brown told me that so far they had made no money, but he was confident there was money in the future. In that stage of the invention, Mr. Holley perceiving its great importance, with his own true-hearted loyalty, went directly to the man who had invented the process to get at the very limit—the utmost outpost of the invention, and we all know how much farther he has carried it.

Afterwards I occasionally met him, so rarely that of course we only entered upon the most ordinary themes of professional interest. Life, and destiny, and the loftier speculations of human thought were never even approached. His character was so lovely, so transparent, it spoke so plainly in his clear, calm eyes and in all his ways, that no one could doubt, at least I entertain no doubt, that he was a sound and true man in every respect, in heart and in character; as we all know him to

have been in his chosen profession. As to his profession, as to the physical sciences generally, it is sometimes made a reproach to them that they fix the attention too exclusively upon phenomena, and therefore ignore essential verities; that appearances are much too opaque, and that behind the veil of appearances there is something undiscerned by the scientific eye. On the other hand, men of science say they see too clearly to be deluded by dreams and superstitions. And, therefore, these concurrent views of the same aspect of human life point in the same direction. They are like two sides of a tapestry. About all this, in connection with Mr. Holley, I know nothing, nor do I care. What is doubt but an ambiguous term? And denial itself is only negative faith, and the sign you know changes by transposition to the other side.

And though to us who "know in whom we have believed," doubt may seem dismal and denial dreary and dark, yet when we see the hollow, shadowy forms, that pass in the name of faith, doubt—denial itself—seems seraphic devotion, beatific vision, compared to that heartless assent and shallow acquiescence which give a too ready *credo* to the incredible. I do not know why I should have said all this of Mr. Holley, because I have not the slightest doubt that upon all that relates to the higher problems of life his mind was clear and poised, fixed upon firm conviction as upon all matters of physical science. I need not say that I loved him; all loved him. "None knew him but to love him, none named him but to praise." And if I should reiterate much that has been better said, as I should have to do to express my feelings, I should say that I have but little to give as a rational basis for those feelings; and therefore I will claim your attention no longer.

THE PRESIDENT: We have with us a gentleman who has come from the West, for the purpose of presenting a tribute to the memory of our friend. Mr. Holloway, I think, is in the room.

MR. HOLLOWAY: It is now nearly twenty years since first I met Alexander L. Holley. At that time, at the request of some gentlemen who were about to establish works in Cleveland for the manufacture of steel by the Bessemer process, I made a visit to Troy for the purpose of witnessing its manufacture there, and to take note of the appliances by which it was accomplished.

Upon my arrival in that city I sought the location of the

steel works, which, as I remember, was in a somewhat rural district below the city, on the banks of the Hudson Arriving at the spot I entered a small wooden building, which seemed to be office, drawing-room, and store-room combined; it contained among other things as I well remember a large table, and one side a row of shelves upon the wall. Upon the table and upon the shelves were short bars of steel, sections of rails, lumps of iron ore, specimen pigs of iron, and pieces of boiler-plate. The bars of steel were bent and twisted into various shapes, and the boiler-plate was flanged backward, forward, and doubled upon itself, and the corners drawn down into small rods, which were tied into all kinds of fantastic loops and knots, all tending to illustrate the wonderful tenacity of the material from which they were made. I knew not where the specimens were made, or where the material came from, but supposed them to be from the newly discovered Bessemer steel as made in England. While looking over the contents of the table Mr. Holley, who had been sent for out in the works, came in. I had read with great interest his paper, the "Railway Advocate," and his work on "European Railways," and had been charmed with his contributions to the New York *Times* over the signature of "Tubal Cain," and I confess I was a little disappointed as I looked upon the slender, young-looking fellow who stood beside the table and before me, but the frank open-heartedness of his manner, his bright hopeful face, and his modest bearing, left an impression upon me years have only deepened, and time will never efface. I was taken through the works by Mr. Holley, and shown all that had been accomplished up to that time, and it was little enough. The works were then idle; they had built one plant and had tried to operate it by water power, and had failed; they had then built another, and a larger one, expecting to work it by steam, but owing to insufficiency of boiler-power and for various other reasons, that had not been a success. I remember how fully and frankly he spoke of all these failures, and how hopeful he was of the future; he said that when they procured new boilers, and changed the blowing engines somewhat, and found a material that would stand for lining the vessels, and come across the right kind of pig-iron, he thought it would be all right. Knowing little or nothing of this new process for making steel, and seeing so little evidence of success in the

surroundings, it seemed to me to be an almost hopeless undertaking. There were only two things about the whole place that looked at all encouraging; one was the table, with its twisted and bent bars of steel, the doubled and knotted specimens of boiler-plate that lay upon it; and the other was, the young man who modestly stood beside them. A few days ago, after an interval of all these years, I again stood within the steel works of Troy. To you who are familiar with the Bessemer steel plant of to-day no description of the place is required, but the contrast between it and its surroundings, and the little experimental works I had visited there twenty years before was marvellous. The quiet, rural surroundings were all wanting; the peaceful air which had previously pervaded the spot had given place to a hum of industry which encircled the whole country about. The very air quivered with the pulsations of immense fans and blowers, which swallowed up the atmosphere by tons and poured it into vast furnaces and converters; ponderous hammers shook the ground you stood upon; or as you picked your way about the works, amid the din of clashing wheels and the escaping steam from out a hundred panting engines, fiery little locomotives chased you over tortuous paths, dragging behind them cars laden with glowing ingots, whose passing left a fierce sirocco in the air; but amid the roar of leaping flames, the brilliant coruscations that filled the air with grandeur and beauty, I saw only the table of long ago with its curious specimens, and the young engineer standing beside it. The history of these intervening years is known to most of you to some extent, but to none has its trials, its disappointments, its struggles, and its failures ever been fully divulged. He who suffered them bore them bravely, uncomplainingly, and the study, the hard thinking, the patience and courage which were so necessary, not only for himself but for those with whom he was associated, can never be fully known by anyone. How the metal that was in the man, as well as the metal he sought for and which lay within the reach of the process he introduced, both have triumphed in these later years you all know. One has made all roadways safe and pleasant, and the other has opened up pathways in all our lives which, lighted up by his genial wit and humor, no coming cloud can now obscure, and which only the twilight of our own lives will mellow ere its light goes out forever.

To the Society of Mechanical Engineers in this the early stage of its existence, the death of Alexander L. Holley is a great loss. How earnestly he interested himself in its formation is known to you all; how valuable would have been his advice and counsel, his spoken and written contributions, had his life and health been spared, all can well imagine. It was ever his constant effort to raise the standard of engineering science, and to elevate to the high position he felt that the engineer was entitled to, all who made it a practice or a profession. You who still possess the engineering paper which, in connection with the late Zerah Colburn, he published in his youth, will find within its yellow faded leaves many an editorial in which he strove earnestly to incite the engineers of that day to make themselves worthy of the position to which their high calling entitled them. His helping hand was ever stretched out to lift upwards, his cheering words went through the ranks urging all to come up higher; and the rich legacy he has left us of an honored and world-respected name, is one which the Mechanical Engineers of America should ever prize. He was the Moses who led us out from the old bondage of cant and custom, which made the engineer a worker only and not a thinker as well. College-bred as he was, donning the costume of the locomotive engineer he mounted the foot-board, and cajoled and manœuvred the rickety engine of that early day over the still more rickety roadbed over which it then ran. It was the saying of a celebrated and somewhat eccentric inventor and engineer, as illustrative of the various conditions of a life which fortune and misfortune had brought to him, that he had at times dined in the palaces of the great, where the plate upon the table was worth a duke's ransom, and so downward through every varying stage of descent to the twopenny bench under a bridge, where the battered iron spoons were chained to the table to keep the guests from stealing them. Inversely, our friend and associate from the foot-board of the little Jersey locomotive made honest, manly strides upwards, until he became the honored, welcome guest in the highest circles in foreign lands as well as in our own. It was not because Alexander L. Holley was a graduate of a college or university that I loved him, it was not because he was a practical workman and engineer, it was not because he was a brilliant and graphic writer, nor was it because he was

as well a learned and argumentative one; not because he could stand up before any society, no matter how technical or scientific, and deliver an essay which for its depth of research, originality and comprehensiveness would rank with the best; it was not for the reason that at the social gathering, where wit, humor, and good fellowship held the hour, that he was the plumed knight about whom all loved to gather, and from whose well-filled quiver he launched repartee and response, and where he parried and thrust with his lance-like wit, hitting everywhere, wounding nowhere; neither was it because he was ever the kind, courteous, considerate gentleman; in short, it was not for any one of these things he won the high regard he so richly deserved; but it was because that he of all the men of his time and age, so far as I know, combined all these commendable qualities in one. The truest test of his goodness now is that in this steady upward march his noble manhood disarmed all criticism, allayed all jealousy, making no enemies, winning all hearts.

Let us remember his fame is our own, winning it as he did by hard study and toil; as he rose to the high eminence he occupied he lifted the profession with him, and the standing of all mechanical engineers the wide world over is higher to-day for the labors of his life, and for the works he accomplished; and if there is any one thing more than another left us to do, it is to emulate his example and to keep his memory green.

The President: I will call upon Mr. Coleman Sellers.

Mr. Sellers: I regret exceedingly that I was not able to come earlier to this meeting so as to hear the addresses delivered by Mr. Bayles and those who spoke later. Probably they covered the ground better than what I can say now. For want of particular knowledge as to what they have told you, it would probably be better for me to confine my remarks to some little instances that occurred in the life of Mr. Holley that may be interesting. My acquaintance with our dear friend began many years ago, when he was connected with Mr. Colburn, as the last speaker remarked, in that little paper which has now become yellow with age. I hardly know how to consider the different events of his life. Looking over a memorandum-book a few days ago, for an entirely different purpose, I stumbled upon a period when Mr. Holley's name seemed to be written on almost every page, and that was the year 1861, at

which time he was imbued with the idea that a locomotive traction engine for common roads would be a very desirable thing; and in connection with Mr. Holley I worked for many months on this traction engine. At that time our forts had been fired upon, and everything was confusion and fear, and it seemed that the whole attention of mechanics would have to be given to furnishing the government with materials for war. It was then that Mr. Holley turned his attention to the more important work of making Bessemer steel. But there is a little incident that I should like to present to you. A gentleman some little while ago, writing from New York, asked me for a definition of "set screw." Unfortunately, he said, he could not find a definition which he could use in a suit at law. I told him he was mistaken, and that the definition could be found in Webster's dictionary; and the reason I knew it, was because Mr. Holley had put it there. Mr. Holley called on me once to have one of those little chats that we used to enjoy so much. He said that he came for the purpose of getting my help in preparing the technical terms on mechanical science for Webster's dictionary. So we went through the shop to get those words, and thus it came that the definition of a "set screw" was one of the terms which Mr. Holley and I worked out together.

Now, all those little things are pleasant recollections to me. It seems as if there was no period in my life as an engineer into which Mr. Holley did not enter. He would come and have a long talk about this society, what was absolutely necessary for its vital existence, and urging the preparation of various papers that would be required; and it was only a very short time before his death that we had one of those delightful conversations. But there was a little talk that I had with him on the Hudson River Road that was so characteristic of the man that I think if I relate that alone it will be sufficient for my contribution to this commemoration of Mr. Holley. We had been up to Troy, and we had gone over the Bessemer Works there. We had dined together, and there was a party of ladies and gentlemen in an apartment of one of the cars. They did not know very well all the places along the road, and made inquiries about them, and finally the conversation turned upon the style of architecture that obtains in some of those beautiful buildings that stud the Hudson. Holley said: "Do

you know I would like some day or another to deliver a course of lectures on architecture applied to mechanics." I said: "I hope you will. How will you handle it?" "Don't you know," he said, "that you and I have had a good many talks about the abominable practice of putting different styles of architecture, Gothic and what not, into steam-engines and other machines. We know perfectly well that what is the most fit is the most beautiful." And so he went on talking in the way in which Holley only could talk about the possibilities of the lecture which would be of eminent use to mechanics in showing the law which obtains in regard to everything, that utility and fitness constitute beauty. Just what nature has done in adapting each tree and each part of it to its proper use is applicable to machinery, and each deviation from that is only an abnormal condition. This was soon after the fire in Chicago and he said: "Have you seen Chicago since the fire? Have you seen the wonderful buildings that have been erected there? Chicago has risen like the Phœnix from her ashes, and yet you will find there the most striking instances of the barbarity of the American people, and their low condition in regard to fitness and propriety. In Chicago they have erected numbers of handsome buildings, and some of the noblest specimens of architecture have been put into their stores and warehouses, but what else have they done? All these beautiful pieces of architectural ingenuity are plastered from top to bottom with signs,—cigars, snuffs, tobacco, dry goods,—covering the whole city of Chicago with black and gold, after putting millions of dollars into those buildings in which the highest skill in construction has been displayed. Now," he said, "we must educate the American people up to such a condition that those things will be impossible. It certainly shows the very low condition of the æsthetic element in the country that they are capable of defacing these beauties with this mere advertisement of their goods in such a glaring way." That was so characteristic of Mr. Holley that I would like very much to see it put upon the record. Had he lived, I think, because he frequently referred to it afterwards, he would ultimately have worked up this particular subject. He would have found many more willing ears to listen to him now than at the time he talked to me. The very thing he advocated so earnestly is having its effect.

It is useless for me to say anything to you about his genial qualities. You all know more about them probably than I do. It is very unfortunate that the city of New York is a great way off from the city of Philadelphia, and we did not see each other as often as we would like to,—Philadelphia being a suburb of New York, of course. But there were times when he would come over here. When he was in London ill, and every steamer was watched to bring the news of his condition, there was one very pleasing thing connected with it all, and that was that gentlemen connected with the paper which his former partner had originally founded (I speak of the *London Engineering*), had taken Mr. Holley to their own home; and when I heard of all the care and comforts that were thrown around him by these brethren of ours on the other side of the water, I must say that I felt heartily grateful to them for all that they had done ; and if any word I am saying now ever reaches there, I hope it will convey at least my thanks for what the people of England did for Mr. Holley while he was in such deep distress. I think, Mr. President, that I can add nothing more, but I have given this as a little tribute to his memory.

The President : In the formation of this Society, there was a good deal of work done in preliminary organization, and, as I remarked at the opening, Mr. Holley had a great deal to do in that preliminary work ; but back of what is known and seen, there is a history under the surface of things unknown and unseen. You remember that the call for the organization of the Society was issued with Professor Sweet, I think, as the moving spirit in the organization. He was assisted by two or three friends ; and among those who have done so much in the preliminary work preparatory to organization is one whose name I find on the list presented by the committee as one of the gentlemen ready to speak, an ex-officer of the Society, the gentleman who took charge of our funds, and who in his connection with the Society became even more than formerly a very intimate friend of our deceased member,—Mr. L. B. Moore.

Mr. Moore : *Mr. President:* In accepting, with diffidence, and, I am not ashamed to say it, in accepting with tears, the opportunity to add a few words to the tributes already paid, if anything can be added that has not been better said, it has

seemed to me that there is no truer way to honor the dead than to point a moral for the living. In the illustrious life, the close of which we meet this day to commemorate, there are two or three characteristics which have especially impressed my mind. One is the genial light-heartedness that not only made Holley so agreeable as a man, but that also helped so largely to make him what he was as an engineer. Nor was he one of those who, by nature doleful and sombre, strive to cultivate a cheerfulness which they do not feel. To me it has always seemed that Holley was one of those men who could never by any stress of circumstances be borne down, or become permanently soured, because he carried within him the ingredients that go to make up mental health and moral sunshine. His mind was not burdened by the habitual croakings and uncertainties and dejections that are so often mistakenly deemed the ripe kernels of thought, when they are only the husks that hide or smother them. Then, too, closely connected with this trait of his character, and reacting upon it, was entire freedom from the petty spites, and personal and professional jealousies, which too often disfigure abilities of even the highest order. Holley's career is additional proof that it is mainly the light-hearted and buoyant-minded men who rule the world. Another reminder that runs logically with this, serves to show us from Holley's example how largely the world's great enterprises are to-day in the hands of young men. Before the age of thirty-three Holley had practically grasped the steel-making secrets which have since changed the methods of trade and transportation, and have influenced all the arts and sciences that are built upon these two great foundations. Let us learn anew from the life of Holley, that though gray hairs are honorable, a great truth, or great discovery, or great work, is not the less worthy because youth is behind it, or at the bottom of it.

The only other thought regarding which I shall presume to add a word of comment is this : Holley's career well illustrates the broadened plane upon which men can in our day meet and study nature. In our modern life creeds and customs are chiefly valued in proportion as we are content to accept them at second hand. A mind like Holley's has little need of creeds, because it is one of the makers of customs for mankind. Living as he did close to the universal heart of nature and read-

ing her secrets as in a half-opened book, it was one of the privileges of Holley's genius to show us that there is in nature a beauty which even art cannot portray, because in this beauty are embodied the forces which make art possible.

With your permission I should like to conclude this thought by reading a few lines, the idea or suggestion of which, singularly enough, dates from a commemorative gathering, at which Alexander Lyman Holley was the moving spirit. Let me entitle it

THE NEW NATURE.

In the old days
Men walked with Nature in the quiet wood,
And found her features beautiful or good,
As were their ways.

Still do they look,
Painter and poet, seer and holy man,
For Nature's self, to find her where they can,—
In field or brook.

But these new days
Ofttimes entice from breezy dale and down
Her wandering feet into the dingy town,
Where chimneys blaze.

Are forge and flue,
Steeple and street, becoming in her sight
More dear than all the joys of day or night,
That once she knew ?

That—none may know ;
Her gifts are hers, to spend them as she will—
Changed, or the same, Nature is Nature still
And chooseth so.

Of all who seem
To seek her face, one asks, whom do her eyes
Rest kindliest on ? Nature herself replies
(So we may deem),

To him that asks :
"The wine is given to him that hath the cup ;
Use is but beauty, girded strongly up
For kindred tasks."

Mr. Albert H. Emery : So much has been said that it would seem needless to add anything further ; yet I should do great

violence to my feelings if, when the opportunity is offered, I should neglect to add at least a word towards giving them expression.

In the construction of the testing-machine, with which my name is identified, Mr. Holley was always ready to listen to my suggestions, and always ready to carry them out, and when the machine was finished he was the first to undertake to put its merits before the public. Unasked by me, he wrote and published at his own expense a little pamphlet, which he read before the Society of Mining Engineers, at their meeting at Baltimore. He was one of the first to recommend Congress to pay me for the machine, and he has done much more than I can tell you to put its merits before the public.

Last summer, just before he started for Europe, I walked into his office one morning. He said, "Emery, I am glad to see you. I am going to Europe, and I want to know if you will allow me to go to some of the European governments this summer and put that testing-machine before them and get some contracts for you?" I said, "Some other time, Mr. Holley; but not now." I was so situated, pecuniarily, at the time, owing to the Government not having paid me as recommended, that I did not care to have him do what he proposed then. But he seemed very anxious to put that machine before those governments. It was a work near his heart, and although he served on that Board a good many days of toil, he gave his valuable time to the public without a dollar of compensation, and when the Board was disbanded it went to his heart more than any other thing I ever heard him speak of. He spoke of it repeatedly, and with a great deal of feeling. He seemed deeply to regret that the Board could not be continued, and he go on with the others in the work which he had seen inaugurated. He has done more for me than I can tell you, and I would like to say a word in regard to this memorial which is proposed for him. It seems to me that the best monument of him is his own work. Mr. Holley has left a great monument, which must endure for all time. But as a member of this Society, and sister Societies with which he was connected, as an American engineer, as one of those engineers with whom he was associated in a profession which he has done more to lift up abroad, than any other man, as a citizen of this country, the wealth of which he has done so much to increase, I say much is due to Holley. I say

it advisedly. None of us, I believe, realize to what extent—millions of dollars—hundreds of millions of dollars,—nay, I think, if a careful estimate was made, thousands of millions of dollars would be found to have been added to the wealth of this country—to its industries, because of the progress of Bessemer steel, which has given us that permanent way which enables us to take our wheat from the Far West and lay it down in the centre of Europe. Without that steel we could not have done this. Without it those millions which have flowed into this country for the last three or four years would not have so flowed. Without it we would not have had this flood of commercial prosperity. To Holley's individual efforts much of this prosperity is due; and I, for one, shall be dissatisfied if this Society, if the other two engineering Societies, if those great Bessemer steel interests, which he has helped to build up, if this great prosperous country, which he has helped to make wealthy, do not unite in raising a monument worthy of one who has done so much for the world. I hope a monument may be put up which will be worthy of this country, worthy of these Societies, and worthy of Holley.

Mr. Partridge: Listening to all that has been said this afternoon, one who knew Mr. Holley only a little and at a distance, as it were, finds the single note recurring over and over again,—disinterested helpfulness. It seemed as though he had lifted everybody's load; and I think I can do little better than to give an instance of the way he would exercise his wonderful inventive ability to do even a little thing. When he wanted to make the Bessemer process known to the students—known to the world, I received through a friend a little card saying that in Hoboken, at such a time, there would be a lecture, by A. L. Holley, on the Bessemer process. I went there and found a lecture-room arranged somewhat like this, with a goodly audience, and a quiet, pleasant man came on the stage at one side. The whole front was filled with a great screen for the lantern, and that pleasant man commenced reading a delightful story of steel and its uses, and began with the details of the Bessemer process, and referred to Figure 1, and the lights went down, and while his voice went on continuously, the lantern flashed out, with a 15-foot diagram of Figure 1; and as he referred to letter after letter, or part after part, the black line of the pointer touched each one in succession.

We had to look and to listen. It went on, and Figure 2 was necessary, and, without a pause, 2, 3, 4, and it went on to 7, 8, 9, and 10, and they made their appearance in their regular order, and every part that the lecturer mentioned was touched by that needle-like shadow. It was teaching in its highest form. Only once in the whole lecture did Holley stop, and that was when, after referring backward to Figure 2, and forward to Figure 7, he turned round to see whether the man at the lantern was still keeping up the diagrams in order. There was not a hitch from the beginning to the end of the lecture. It was like magic. It was a system of illustrative lecturing so superior to anything that I had ever seen before, or ever heard of, that I thought it was enough to have made an ordinary lecturer's fortune, and all to enable the student to understand easily the Bessemer process.

MR. SELLERS: I would like to ask if the Hon. Mr. Wayne McVeagh is here.

THE PRESIDENT: Is Mr. McVeagh here?

MR. SELLERS: A few days ago, I met him and told him of this memorial meeting, and he bowed his head with sorrow for his friend. He said that he would try to be here; that nothing would give him so much pleasure as to say a few words about one whom he valued so highly, not only as a personal friend, but as a man who had done so much for the industrial welfare of the country. If Mr. McVeagh is not here, I should like at least that there may be a record of what he wished to say.

LX.

DETERMINATION OF HEATING SURFACE REQUIRED IN VENTILATING FLUES.

BY

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THE proper ventilation of a room requires the frequent removal of the vitiated air and the introduction of fresh air, the quantities by weight of the air ejected and the air introduced being equal. If the process be continuous and the proper

amount of air be admitted and removed every hour, or minute, the only other requirements are that the entering air shall be pure, that it shall be properly warmed in cold weather, either before it enters the room or by the mixture of warm and cold air in the room, and that the introduction and removal of air shall take place by gentle or inappreciable currents, distributed in such a manner that the pure air may be thoroughly diffused throughout the room before it is removed.

These simple rules are easily stated and comprehended. It is also well understood that the movement of air requires force in proportion to the mass moved and the velocity which is imparted to it. The problems which arise in ventilation consist mainly in determining the positions, arrangements, and sizes of the passages through which the air enters and leaves the space ventilated, and the adaptation to the passages or flues of the force or forces which produce the movement of the air. On the solution of these problems, too often misapplied or misunderstood, successful ventilation depends.

The various means of producing the movement of the air are:

1st. *Fans or blowers*, requiring the use of machinery in driving them.

2d. *Ventilating chimneys*, in which the movement of the air is caused by the difference in weight between the columns of hot air in the flue and the cooler air outside. This requires necessarily that the air in the flue shall be warmer than that outside, and the necessary heat must be imparted to the air before it enters the flue.

3d. The movement of the air may be produced by *steam jets* in the flue, the particles of steam issuing at a high velocity, carrying with them particles of air, and thus producing a diminution of pressure below the jet and a consequent movement.

The steam jet method is seldom used, the ventilating flues being generally employed. The most common application of the latter is the ordinary ventilating flues of dwelling-houses. In this case reliance is usually placed upon the heated air of the room, which, finding its way into the flues, forms a vertical column lighter than the outer air, and having a height equal to the height of the flues. An upward movement in the flues is thus produced.

The laws of the movement, involving the height of the flues, the temperature of the air in the room, the temperature of the outer air, and the velocity of the upward current, may in this case be theoretically determined; and from such a determination, taking into account the frictional resistances, the area of the cross-section of a flue for the discharge of a given weight of air may be ascertained. Analytical investigations of this character are seldom made except by experts, and for ordinary dwelling-houses the whole system is generally a haphazard construction, in which the errors are quite certain to fall on the side of inefficient ventilation. Moreover the system cannot operate during those periods of the year in which the temperature of the outer air is the same or nearly the same as that of the room. During these seasons some other means must be resorted to in order to warm the air before it enters the vertical ventilating flues. The system is inefficient also, except with very large flues, owing to the slight difference, even in ordinary cold weather, between the temperature of the air in the room and that of the air outside.

For very active ventilation, therefore, with such flues as may ordinarily be constructed, the air must be heated; and this may be done by several methods:

1st. By a stove at the base of the flue, the stove-chimney passing up through the flue.

2d. By gas-jets burning at the base.

3d. By coils of steam-pipes in a chamber at the base of the flue.

All of these processes require careful analysis in their application, and may, to a certain extent, be subjected to such an analysis. The object of this paper is to investigate the laws which govern the ventilation when the air is heated by means of coils of steam pipe, before it enters the flue. These laws have not heretofore been developed, and as this system of ventilation is a very simple one, capable of extended application, it is hoped that the following analysis may at least lead to a full discussion of the subject.

Let it be supposed that the air in the room is to be renewed at the rate of W pounds per second. The volume of this quantity of air can easily be determined when its temperature is given. Suppose also that it is to be ejected through a vertical flue whose cross-section is A and whose height is H, and

that it is to be heated by steam-coils at the base of the flue, having a total exterior surface equal to S.

The following notation will be used :

W = weight of air discharged per second.

H = height of flue.

S = the exterior surface of steam-coil.

A = area of cross-section of flue.

T_a = the absolute temperature of the external air, *i. e.*, the common temperature Fahrenheit + 459.4°.

T_c = the absolute temperature of the air in the flue.

T_s = the temperature of the steam in the coils.

D_a = the weight of a cubic foot of the external air.

D_c = the weight of a cubic foot of the air in the flue.

V' = the theoretical velocity of the air in the flue.

V = its actual velocity when frictional resistances are taken into account.

r = the rate in units of heat per hour for each square foot of the surface S, at which the air receives heat from the coil, and for each degree of difference between the temperature of the steam and the air of the room.

K = a coefficient of velocity, such that $KV = V'$.

p = the unbalanced upward pressure at the base of the flue due to the difference between D_a and D_c, or due to the difference in weight between the two volumes of the height H within and outside of the flue.

The pressure per square foot, p, will then be represented by the equation,

$$p = HD_a - HD_c \text{ or } p = H(D_a - D_c) \quad . \quad . \quad . \quad . \quad (1.)$$

This pressure may be represented by the weight of a column of the heated air, represented by

$$\frac{p}{D_a} = H\left(\frac{D_a - D_c}{D_c}\right) \quad . \quad . \quad . \quad . \quad . \quad (2.)$$

The velocity with which the air would flow through the flue if there were no resistances would be determined by the expression,

$$\frac{V^2}{2g} = H\left(\frac{D_a - D_c}{D_c}\right)$$

$$V = \sqrt{2gH\left(\frac{D_a - D_c}{D_c}\right)} \quad . \quad . \quad . \quad . \quad . \quad (3.)$$

But from the Mariotte-Gay Lussac law for air,

$$\frac{D_c}{D_a} = \frac{T_a}{T_c} \text{ or } D_c = D_a\left(\frac{T_a}{T_c}\right)$$

Substituting this value of D_c in equation (3), there results

$$V = \sqrt{2gH\left(\frac{T_c - T_a}{T_a}\right)} \quad . \quad . \quad . \quad . \quad . \quad (4.)$$

In this expression the theoretical velocity is expressed in terms of the absolute temperatures of the air within and without the flue, and the height of the flue.

From (4) we obtain

$$T_c - T_a = \frac{V^2}{2gH} T_a \quad . \quad . \quad . \quad . \quad . \quad (5.)$$

The quantity of heat transferred to the air on its passage through or among the steam-pipes may be represented by

$$Q = WC(T_c - T_a) \quad . \quad . \quad . \quad . \quad . \quad (6.)$$

in which $C = .238$, the specific heat of air at constant pressure.

All of the above formulas are well known; the following are believed to be new:

The quantity of heat imparted per second to the air by the steam-pipes may be represented by the total exterior surface of the steam-pipes (S) expressed in square feet, multiplied by the rate per second and per square foot at which heat is transferred to the air, or

$$\frac{S_r(T_s - T_a)}{3600} = Q'$$

and from the nature of the problem we must have $Q = Q'$

or

$$\frac{S_r(T_s - T_a)}{3600} = WC(T_c - T_a) \quad . \quad . \quad . \quad . \quad (7.)$$

from which we obtain

$$T_c - T_a = \frac{S_r(T_s - T_a)}{WC \times 3600} \quad . \quad . \quad . \quad (8.)$$

Combining this equation with equation (5) we have

$$\frac{S_r(T_s - T_a)}{WC \times 3600} = \frac{V^2}{2gH} \times T_a$$

and

$$S = \frac{V^2}{2gH} \times \frac{WC\,T_a}{\frac{r(T_s - T_a)}{3600}} \quad . \quad . \quad . \quad . \quad . \quad (9.)$$

This expression gives the total heating surface of the steam-pipes in terms of the velocity, the height of the flue, the weight of air discharged per second, and the absolute temperature of the external air.

If we substitute for V' its value KV, the expression becomes

$$S = \frac{K^2 V^2 \times W C T_a}{2gH\left(\frac{r(T_s - T_a)}{3600}\right)} \quad . \quad . \quad . \quad . \quad (10.)$$

and since V is the actual velocity, we have

$$W = D_c V A$$
$$\therefore S = \frac{K^2 V^3 \times D_c C T_a A}{2gH\left(\frac{r(T_s - T_a)}{3600}\right)} \quad . \quad . \quad . \quad (11.)$$

A being the area or cross-section of the flue. Equations (10) and (11) represent the laws connecting the heating surface with the height of the chimney, the area of the flue, and the temperature of the external air. They show that the heating surface is directly proportional to the cube of the velocity, to the area of the flue, and to the temperature of the external air, and inversely proportional to the height of the chimney and the rate of transfer of the heat, r or $_r\ (T_s - T_a)$.

To illustrate the practical use of the formula, let it be proposed to renew the air of a room containing 50,000 cubic feet four times in an hour, through a flue whose cross-section $A = 12$ square feet, the height (H) being 50 feet. Required the number of square feet in the surface of the coil, the steam within the coil being maintained at 50 pounds pressure. Suppose, further, that the temperature of the air, before it enters the flue, is 60° F., the same as that of the outside air.

The weight of a cubic foot of air at 60° F., or (D_a), is found as follows: The weight of a cubic foot of air at 32° F., and atmospheric pressure being known, viz., 0.0808 pound, the weight at 60° F., will be

$$D_a = 0.0808\ \frac{T_c}{T_a}$$

T_c being the absolute temperature corresponding to 32 F. (or 32° + 459.4° = 491.4°), and T_a being equal to 60 + 459.4° = 519.4°,

$$\therefore D_a = 0.0808\ \frac{491.4}{519.4} = 0.0764 \text{ lbs.}$$

and the weight of 50,000 cubic feet at 60° F. will be

$$50000 \times 0.0764 = 3820 \text{ lbs.}$$

As four times this weight is to pass through the flue in one hour, we have

$$3{,}820 \times 4 = 15280 \text{ lbs. per hour;}$$
$$\text{or } 254.67 \text{ lbs. per minute;}$$
$$\text{or } 4.244 \text{ lbs. per second.}$$
$$\therefore W = 4.244 \text{ lbs.}$$

We also have

$$T_s = 519.4°$$
$$C = 0.238$$

For the value of r to be used in the formula, and average of the results of the experiments made by Mr. C. B. Richards, at the Colt's Arms Co., at Hartford, may be taken for ordinary forms of heaters, it being understood that this value is assumed to be nearly correct, although the quantity (r) was found to vary in proportion to the quantity of air passing through the heater in a given time. Assuming the value of (r) to be 2.5 units of heat per hour per square foot of surface, and for each degree difference of temperature between the steam in the coil and the air of the room, there results for the value of r per second,

$$\frac{r}{3600} \times (T_s - T_a)$$

with steam at 50 pounds,

$$T_s - T_a = 281° - 60° = 221° \text{ F.}$$

$$\therefore \frac{r}{3600}(T_s - T_a) = \frac{2.5}{3600} \times 221 = 0.153$$

All the quantities in equation (10) are now known for this problem, except $K^2 V^2$. If we assume a velocity V, and also a correct value of K, the resultant value of S should be such as to give this velocity. Assuming $V = 7$ feet per second, and $K = 4$, the value of $K^2 V^2$ will be $16 \times 49 = 784$.

In regard to the value of K, Peclet found in the ordinary boiler chimney of manufacturing establishments, for heights of 10, 20, and 30 meters, V' equal respectively to 5.6 V, 6 V, and 6.3 V. It may also be demonstrated that if the resistances were due to friction alone, the loss of velocity in a simple rectangular flue, 50 feet high and 12 square feet cross-section, would be such that V' would be about twice V, or $V' = 2V$.

The interposition of the coil of pipe through which the air

passes increases the resistance beyond that of the simple flue, but it cannot be so great as that developed in passing through the grate, flues, and chimney of a steam-boiler.

I have taken for this example $V' = 4\,V$, *i.e.*, the actual velocity equal only to one-fourth of the theoretical, which will at least throw the error, if there be any, on the side of excess in the value of S.

We may now recapitulate the values of the quantities in equation (10) as determined for this problem.

$$K^2\,V^2 = 784.$$

$$\frac{r\,(T_s - T_a)}{3600} = 0.153$$

$$W = 4.244.$$

$$C = 0.238.$$

$$T_a = 519.4°.$$

$$\therefore S = \frac{K^2\,V^2 \times WC\,T_a}{2\,gH.\,\frac{r\,(T_s - T_a)}{3600}} = 835 \text{ square feet.}$$

It now remains to ascertain what temperature and density the air in the flue will have.

The quantity of heat expended per second will be :

$$S \cdot \frac{r\,(T_s - T_a)}{3600} = S \times 0.153 = 835 \times 0.153 = 127.755 \text{ units.}$$

Per minute it will be 7,665.30, and per hour, 459,918 units.

To find the flue temperature (T) we have

$$Q = (WCT_c - T_a)$$

$$\text{or } T_a = \frac{Q + WCT_a}{WC} = \frac{127.755 + 1.01 \times 519.4}{1.01} = 645.9°,$$

corresponding to a thermometric temperature of $645.9 - 459.4 = 186.5°$. This is the temperature of the air in the flue. Its density will be

$$D_c = 0.0808\,\frac{T_c}{645.9} = 0.0808\,\frac{491.4}{645.9} = 0.0614 \text{ lbs. per cubic foot.}$$

The volume of one pound will be $\frac{1}{0.0617} = 16.28$ cubic feet.

With a velocity of 7 feet per second there will be ejected through the flue of 12 square-feet area, 302,400 cubic feet, or $302{,}400 \times 0.0617 = 18{,}567.36$ pounds per hour.

This is in excess of the requirement, which was only 15,280 pounds per hour.

If we assume a velocity of 5 feet per second, the discharge of heated air will be $12 \times 5 \times 3600 = 216{,}000$ cubic feet per hour. The resistance to the flow will be diminished nearly in proportion to the square of the velocities, and we shall have $K^2 V^2 = 9 \times 25 = 225$. The value of r will also be somewhat diminished, and may be taken as 2, so that $r\frac{T_1 - T_2}{3600} = 0.123$.

$$\therefore S = \frac{225 \times 4.244 \times 0.238 \times 519.4}{64.4 \times 50 \times 0.123} = 297. \text{ square feet.}$$

The heat expended per second will be $297 \times .123 = 36.53$ units per second, 2191.8 per minute, 131508. per hour.

$$T_c = \frac{36.53 + 1.01 \times 519.4}{1.01} = 555.5° = 96° \text{ F.}$$

$$D_c = 0.0808 \times \frac{491.4}{555.5} = .0719.$$

The theoretical velocity in the last case will be

$$V = \sqrt{2g \times 50\left(\frac{555. - 519.4}{519.4}\right)} = 15 \text{ feet per second;}$$

i.e., three times the actual velocity, which was assumed to be 5 feet.

The weight of air discharged will be $216000 \times 0.0719 = 15530$ pounds per hour, only slightly in excess of the quantity required, which was 15280 pounds.

It will be seen that the quantity K^2, the coefficient of the square of the velocity, and in regard to which the most uncertainty exists, has an important influence on the quantity S. It seems probable that a value of K between 3 and 4, or of K^2 between 9 and 16, will answer for all ordinary cases, and that a value of r between 2 and 2.5 will be approximately near enough. The smaller values correspond to low velocities and large flues, and the larger values to high velocities and smaller flues.

If the value of V be assumed as 5 feet per second, and that of K as 3, or K^2 as 9, then by combining the constants in equation (10) we may write approximately,

$$S = 1500.\frac{W T_a}{H(T_1 - T_a)}$$

and for the area of the cross section of the flue or flues for a given discharge (W) we have

$$A = \frac{W}{D_c V}$$

in which V, the velocity, is 5 feet per second.

These last equations are suggested as working formulæ under ordinary circumstances. Further experiments are desirable for ascertaining the values of K and r under ordinary conditions of the problem; still the formulæ, while only approximately correct, exhibit the laws which control the movements of the air.

To compare this method of ventilation with that by means of a fan or blower, let it be supposed, as found in the last example, that the heating surface required is, in round numbers, 300 square feet. The quantity of heat transferred per second would be 300×0.123 nearly, or about 36.9 units of heat; per hour, 132840 units. If we estimate in round numbers about 1100 units to raise the temperature of water from 60° and evaporate it at 281°, corresponding to 50 pounds pressure, we shall have $\frac{132840}{1100} = 120.7$ pounds of water necessary to produce this amount of heat. Estimating 1 horse-power per hour at 40 pounds of water evaporated under the same conditions, the heat expended for ventilation would furnish in an engine about 3 horse-power.

Compared with the estimates of the horse-power required for a Sturtevant blower to produce the same effect, the steam-coils are more economical than the blowers. There seems to be no doubt that steam-coils properly devised and adapted to chimneys or flues will give more efficient ventilation than the blower, for less cost of construction and maintenance.

A more extended discussion of this subject might be given, especially with reference to the constants in the equations; but the object of this paper is merely to open the discussion of the subject and to point out the correct method of treating the problem.

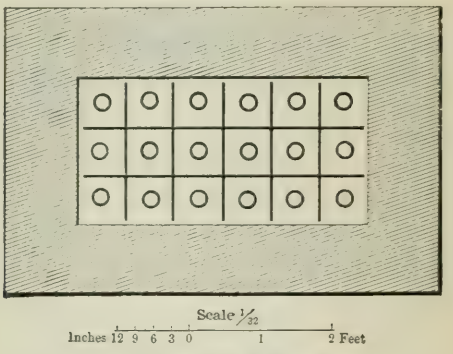
The arrangement of the steam-pipes in such a manner that the greatest amount of heat will be transferred to the air with the least resistance to its motion, is a matter of importance. It is desirable, if possible, to place these pipes within the flues, and it is a difficult matter to introduce the requisite

amount of heating surface, if dependence is placed solely on the direct contact of the air with the steam-pipes.

The following plan is suggested for overcoming the difficulty. It has not, as far as I am aware, been heretofore practiced. Vertical pipes, which are to contain live steam, are introduced into the flue, extending five, ten, or twelve feet upward in the flue. These are separated by sheet-iron diaphragms, which receive heat from the steam-pipes by direct radiation.

The flue is thus divided into several smaller flues at its base, the whole surface of these smaller flues, as well as the walls of the main flue, acting as heating surface. Air does not receive heat by radiation, but, on the other hand, it does not obstruct the radiation of heat.

The figure below (Fig. 2) shows how a large amount of actual



Cross-section of Flue.

Fig. 2.

heating surface with a minimum amount of steam-pipe may be introduced into the base of a flue. In this case the flue has a cross-section of eight square feet, and it contains eighteen vertical steam-pipes, each 2 inches in diameter and 12 feet long, the pipes being closed at the top with suitable air-valves.

By means of the diaphragms shown, the actual heating surface with which the air comes in contact, is as follows: for each foot in height (of the 12 feet) of flue occupied by the pipes.

For the steam-pipes, $\frac{5}{10} \times 18 = 9$ square feet.

For the walls of the diaphragms, including the flue walls, $2'.66 \times 18'. = 47'.88$ square feet.

Total per foot height, . . . 56.88 square feet.
Total for twelve feet high, . . . 682.56 "

Thus, for a total exterior surface of steam-pipes of 108 square feet, an actual efficient surface for heating the air is obtained of 682.56 square feet.

This surface may not all be as efficient as the surface of the pipes, but when it is considered that steam-pipes can give off heat by radiation without losing very sensibly their efficiency of heating air by contact under the conditions here given, it is evident that the surplus surface obtained by the diaphragms ought to compensate for the diminution of active pipe surface. Experiments alone will determine this question, but there seems to be no scientific reason why the device should not be effective.

In this case it will not be difficult to determine the coefficient of velocity K by actual calculation from known data.

Discussion.

A Member: Some years ago it was very customary to ventilate mines by shafts with heating furnaces at the bottom. That principle has been superseded by fans driven by engines, and it seems to me the paper just read subverts that theory, and would suggest the wisdom of going back to earlier and abandoned practice.

Professor Hutton: I think it only fair to state, in discussing that question, that a calculation by this system where the coil is at the base, and the draft depends on the height of the column, would be different from what would exist if you were calculating a suction fan for ventilating purposes. It is in a comparison with the fans for *forcing* as applied for mining purposes,—that is, where we attempt to force the air up the column by a fan at the bottom,—that we should find this great relative efficiency for the coil. If we could put the exhaust arrangement at the roof of a building, I think we would find less difference in favor of the coil.

It simply refers to a case where it is not practicable to have machinery up towards the roof; but where the fresh air must be forced in by the forcing system, that this comparison seems to be fair.

LXI.

EFFICIENCY OF TURBINES AS AFFECTED BY FORM OF GATE.

BY

SAMUEL WEBBER, MANCHESTER, N. H.

THE accompanying tables and diagrams are presented to show the different results produced by two different turbine wheels, of essentially the same form of bucket, and due to the mode of delivering the water to the wheel.

Both wheels are of the class known as inward and downward discharge, but in the case of the National wheel, the chutes or passages are formed in groups of four, and one passage of each group is closed entirely by the same operation, leaving the others entirely unobstructed until all are successively closed or opened by four movements of the gate.

In the Burnham wheel, the water is partially cut off from every passage at the same time, and the result is, as is also shown in the Fourneyron, and various other wheels, that the first partial closure, say to seven-eighths of the gate opening, makes very little difference in the amount of water passing the wheel, while, when the gate is only one-fourth opened, nearly one-half the whole amount of water passes through the gate.

This effect is noticeable in all the turbines, whether cylinder or register gate, in which the passage of the water is cut off by a sharp edge, leaving an angle behind it, in which the entering water can form an eddy, and thus break the full force of the uniform blow, which seems to be essential to good results in any form of turbine.

This effect of throttling the water with an edged gate, has long been known to the builders of turbines, and has led to various devices for diminishing the quantity of water delivered to the wheel, while at the same time maintaining a smooth and unbroken current.

The hinged gate of the Leffel, and other wheels, is one of the most common devices, and answers its purpose very well, the great objection to it being its liability to leakage from wear of joints and hinges.

The Swain and Risdon wheels, have cylinder gates with an outside garniture attached, which prevents the current from being abruptly broken, and have both attained very high results at partial gate, and the bucket of the Swain wheel may be considered as the type which has been generally followed, with some variations, in all the later turbines which have proved of any value.

Figure 4 shows the efficiency of a group of wheels when the water is cut off by a sharp edge, and Diagram 5 of a group in which the water passage has been preserved without a sharp cut-off, as far as possible, and the gates, whether cylinder or register, so arranged as to maintain a smooth volume of water directly to the opening of the buckets, while gradually diminishing its quantity as the gates are closed, and the results in efficiency at part gate, are very noticeable on comparison of the two diagrams.

Test of Burnham "Standard" Turbine, 54 inch diameter, at Works of Douglass Axe Co., September 17th, 1881. Brake circle, 50 Feet in Circumference. Cubic feet of Water Corrected per Velocity of Approach. Weir 12 feet long.

Full Gate.	Weight in scale.	No of Rev.	Rev. per min.	Head on wheel.	Head on weir.	Cubic ft. water per min.	Horse Power water.	Horse Power wheel.	Per cent. effect.
1	450	250	77.72	10.063	1.268	3417.05	64.95	53.	.8160
2	480	"	75.77	10.035	1.274	3441.56	65.23	55.10	.8447
3	500	"	73.17	10.03	1.283	3477.80	65.89	55.43	.8413
4	530	"	68.8	10.	1.284	3481.73	65.77	55.25	.9420
5	550	"	64.65	9.97	1.292	3514.12	66.18	53.88	.8142
⅞ Gate.									
6	400	"	81.52	10.06	1.220	3228.15	61.31	49.40	.8053
7	450	"	76.14	10.02	1.288	3288.46	62.24	51.91	.8353
8	480	"	73.	10.01	1.245	3322.68	62.92	53.09	.8440
9	500	"	71.09	10.	1.249	3342.06	63.13	53.86	.8532
¾ Gate.									
10	400	"	73.89	10.07	1.166	3018.07	57.41	44.78	.7800
11	430	"	69.77	10.08	1.175	3053.81	58.14	45.45	.7817
12	380	"	76.72	10.11	1.156	2980.57	56.92	43.87	.7707
⅝ Gate.									
13	300	"	78.74	10.205	1.078	2674.31	51.55	35.79	.6943
14	330	"	74.25	10.19	1.085	2700.70	51.98	37.13	.7143
15	350	"	70.75	10.18	1.094	2733.46	52.56	37.50	.7135
½ Gate.									
16	250	"	75	10.315	.988	2350.81	45.80	28.41	.6203
17	270	"	66.09	10.30	.994	2371.69	46.14	27.04	.5860
¼ Gate.									
18	150	"	68.18	10.54	.796	1697.14	33.71	15.50	.4598
19	120	"	74.62	10.56	.786	1664.86	33.71	13.37	.4440

Test of "National" Turbine, 50 × 15 inches, at Douglass Axe Co.'s Shops, September 8th, 1881. *Brake circle, 50 feet in circumference. Cubic feet of Water Corrected per Velocity of Approach. Weir, 15 feet long.*

Fall Gate.	Weight on scale.	No. of Rev.	Rev. per min.	Head on wheel.	Head on weir.	Cubic ft. water per min.	Horse Power water.	Horse Power wheel.	Per cent. effect.
1	450	500	85.23	10.54	1.096	3669.53	72.77	58.11	.7985
2	400	"	93.75	10.52	1.1066	3719.51	73.62	56.82	.7718
3	500	"	78.53	10.48	"	"	73.34	59.50	.8111
4	480	"	80.86	10.44	1.104	3709.39	72.78	58.81	.8080
5	550	"	70.47	10.40	1.124	3809.81	74.56	58.68	.7872
6	530	"	67.63	10.41	1.129	3835.66	75.14	59.93	.7977
¼ Gate.									
7	400	"	73.71	10.72	.947	2952.92	59.56	44.67	.7500
8	380	"	77.32	10.57	"	"	58.73	44.52	.7581
9	390	"	75.95	10.56	.953	2980.69	59.21	44.88	.7579
½ Gate.									
10	250	"	74.257	10 807	.747	2065.21	41.99	28.13	.6698
11	240	"	76.53	"	.741	2040.43	41.49	27.84	.6710
¼ Gate.									
12	120	250	67.57	11.56	.4915	1100.18	23.93	12.28	.5132
13	100	250	74.534	"	.492	1101.87	23.97	11.29	.4710

LXII.

THE APPOINTMENT OF A UNITED STATES GOVERNMENT COMMISSION OF TESTS OF METALS, AND CONSTRUCTIVE MATERIALS.

BY

THOMAS EGLESTON, PH.D., NEW YORK CITY.

At a Convention of the Society of Civil Engineers, held June 4th, 1872, in Chicago, it was resolved to ask the United States Government for a commission to test iron and steel and other metals, with a view of ascertaining their properties, as the tables of constants which had been used for a long time in calculating the strength of metals were found to be either inaccurate or in some instances inapplicable to the cases now existing, and their use known to have caused a number of disasters which had resulted in the serious loss of property and life. On March 4th, 1875, Congress granted the prayer of the Society of Civil Engineers and created a commission of seven members, to be appointed by the President of the United States, to test iron and steel and other metals, and appropriated $75,000 for this purpose. It was understood at the time

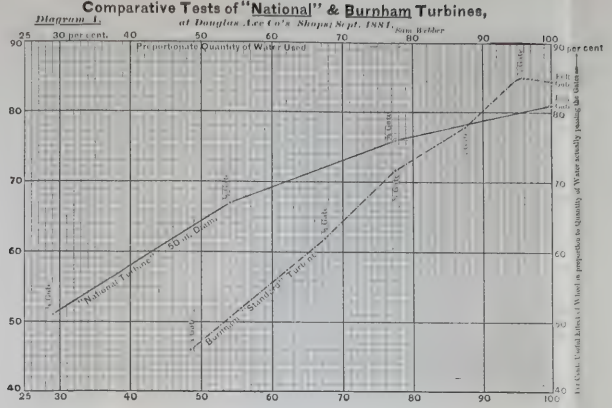

Comparative Tests of "National" & Burnham Turbines,
Diagram A.
at Douglas Ace Co's Shops, Sept. 1887. Jas. Webber
Proportionate Quantity of Water Used
National Turbine
Burnham
Per cent.

Fig. 3.

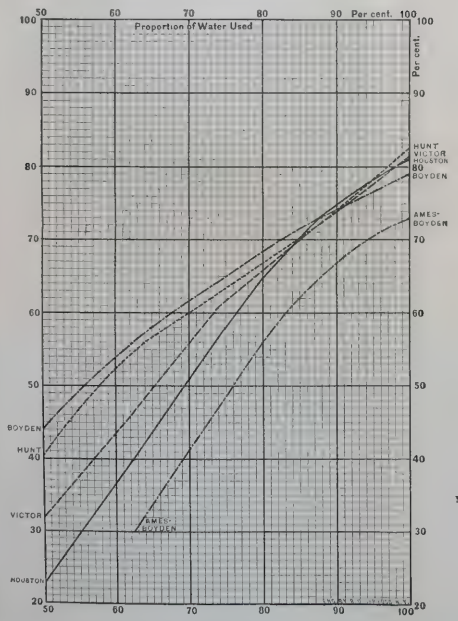


Fig. 4.

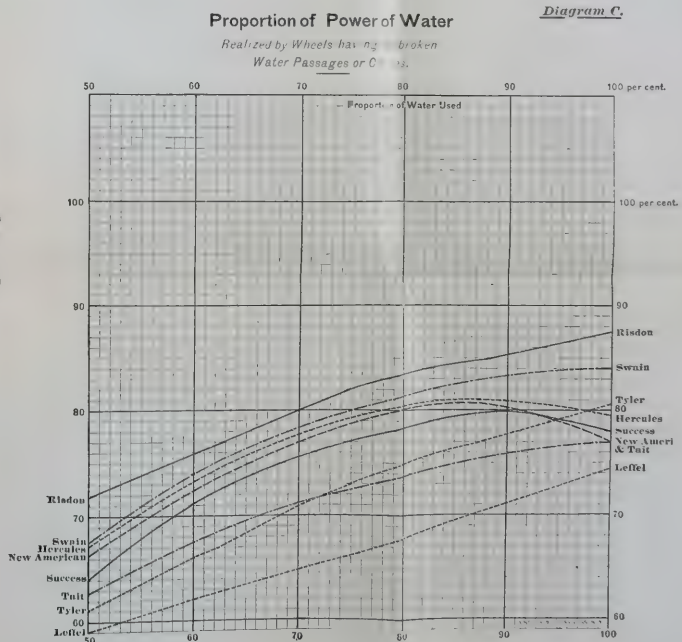


Fig. 5

that one of the chief objects of this commission was to build a testing machine more powerful and more accurate than any that had ever been constructed heretofore. The contract for the construction of this machine was made almost at once, and an appropriation made from the funds granted by Congress for the purpose, which was, however, eventually found to be altogether too small. By the time that this machine was set up and proved to be not only wonderfully accurate, but altogether the most remarkable machine for this purpose that had ever been built, the funds appropriated by the Government had become exhausted. Nearly all the engineering and scientific bodies, including very many of the colleges and technical schools, then petitioned the Government for a further appropriation for the work of the commission. At this point great opposition was developed against the commission from certain quarters that are well known, but as the result of the effort the Senate, in July, 1876, passed a bill appropriating $70,000 to continue the work of the commission. In the House, however, the opposition to the measure was such that they cut down the appropriation to $19,376.98, and limited the existence of the board to June 30th, 1879, at which time, the term of the board having expired by legal enactment, it was dissolved and ceased to exist. It was legislated out of existence just as it commenced to do the work for which it was created. It is useless now to review the reasons why it was not allowed to continue a work in which every engineer in every land was so thoroughly interested, and from which the commercial world would have derived so much benefit and profit. Every engineer knows how uncertain constructive materials sometimes are, hence we cannot always tell beforehand what they will do. It was hoped that the commission would investigate, and remedy some of these defects. If there is any criticism to be made of it, it is that it delayed its work, waiting for the testing machine. I do not mean in any way to imply a censure of the old commission. We stand to-day, owing to its labors, in an altogether different position from when it commenced its investigations, owing to the work it did, and every American engineer may be justly proud of what it accomplished. During the four years that it existed as a board the commission built, on an entirely new principle, the testing-machine which is now at the Watertown Arsenal, which when a few additions to it have been made will

be the most remarkable machine of this kind that has ever been constructed, the result of the work on which has been to revolutionize most of our ideas upon the methods of testing the metals. They made one hundred and fifty analyses of iron and steel; they examined the methods of producing chain cables, reported upon the relations and conditions of certain alloys of copper, and caused to be made a large number of compounds, to investigate the effects of varying proportions of the ingredients usually found in the metals and alloys in common use, many of which, though made at great expense, have never been studied, for the board was legislated out of existence before they had time to use the testing-machine to any extent or to examine any very large number of the alloys and compounds, which had been manufactured for them with great liberality by many of the best manufacturers in the country, at a large expenditure both of time and money. Some of their work has been published, but it is very difficult to get the reports, which should be reprinted; some of it, it is feared, is already lost, and must be done over again if we are to have it at all, or know which of the compounds or alloys have no present value.

The testing-machine has, by law, been allowed to be used by private parties, and a very large amount of material has already been tested upon it by them, it being kept almost constantly employed by engineers of companies who wish to test their material before they use it. But while this machine is the most accurate one that has ever been built, it is very expensive to use it, costing nearly twenty-five dollars a day, but after the work is done, it is not only extremely accurate but all the work done on it at any time can be compared with any other work done at any previous period, a condition of things which up to this time has never existed. If the work of the commission had produced no other result than to prove that reliable and comparable data could only be obtained on full-sized pieces, and that other testing-machines constructed to work on specimens of reduced area which have been used up to the present time, not only do not give comparable results, but that many of them, from faulty construction, are in themselves entirely unreliable, the board would have done all that could have been reasonably asked of it. If this machine, however, or any number of machines like it, is kept constantly in use by private parties, the public will not necessarily be any

the wiser for the work done, for the reason that although the expense of such investigations is much greater when done by private individuals than by a commission, these results will not usually be published, nor will the criticism of engineers generally be invited or obtained.

The work which is necessary to be done could not possibly have been accomplished in the short time in which this board was in existence, even supposing it had found the testing-machine constructed on the day it commenced to work. Such investigations can only be done with the greatest deliberation. It not only takes a great deal of time and thought to plan them, but it takes a longer time to ascertain what the results mean after the experiments have been made. It is, therefore, proposed that the new board shall publish the results monthly, but shall make no effort to draw any conclusions until, assisted by all engineers who are interested in these experiments, they have both been accumulated in sufficient numbers and have been criticised and discussed long enough to make their conclusions worthy of the acceptance of the engineering world.

It has wisely been said that no structure is stronger than its weakest part, and it very often happens that on account of defects in its manufacture, or a want of the knowledge which the work of such a board would give to the manufacturer, this weakest part may be crippled by strain, even before it is used. It may therefore be, and has very often been the case, that a single piece of defective material, whose defects should have been ascertained before it was used, has caused great disaster, and it should be one of the provinces of such a board as this to ascertain beforehand how such weakening may be discovered before the pieces are used.

It is necessary also that this board should examine not only the quality and the quantity of the metals which are used, but also their form. It does not follow that because we have been using certain forms for certain metals that these are of necessity the best; but the form in which the metal is used for commercial operations, every one knows, has the greatest possible influence not only upon its strength but also upon its durability. No better illustration can be given of the proper use of material than a rye straw. In its natural shape it will bear several ounces, if the weight is applied vertically, but if the same amount of material had been collected in a solid form,

the weight that it could possibly bear would be almost nothing. It does not follow at all that we have been of necessity using the best forms for our metals, but it is more than likely that we could use less weight in a different shape, and yet have the piece stronger. What we wish to arrive at in these investigations is not so much to know why a structure fails after it has failed, or to ascertain the cause of the falling of buildings and bridges after there has been a great destruction of life and property, but so to form and arrange the materials that we may be certain beforehand that the constructions will not fail, and that there will be no disaster.

To give some idea of the value of the researches of such a commission, I have extracted from the Report of the last Census a few items relating to the iron and steel industries of the United States, during the year 1880.

Amount of capital invested,	$230,971,884.00
Value of the materials used,	191,271,150.00
Value of the products,	296,557,685.00
Wages paid,	55,476,785.00
Number of hands employed,	140,985.00
Number of works producing,	1,005.00
Total production,	7,265,140 tons.

This amount of total production is divided as follows:

Pig-iron product,	3,781,021 tons.
Products of the rolling mills,	2,353,248 "
Bessemer steel,	889,896 "
Open-hearth steel,	93,143 "
Crucible steel,	70,319 "
Blister steel,	4,957 "
Blooms and bar iron from the ore,	37,633 "
Blooms from pig and scrap,	34,924 "

In the rail manufacture there were produced:

Iron rails,	466,917 tons.
Bessemer steel rails,	741,475 "
Open-hearth steel rails,	9,105 "
	1,217,497 "

Of structural irons, 96,810 tons were produced. There were used in the year 1881 for the construction of bridges 80,000 tons of iron and steel, representing fifty consecutive miles of structure, over which the public travel with such a

perfect feeling of security that they scarcely ever give a thought to the possibility of danger. Yet it not unfrequently happens that these structures give way, producing great disaster to life and property, which it is believed that the researches of a commission of this kind might prevent. Of very large beams used in the floors of buildings over 50,000 tons were used. Many of these were used in structures which were considered perfectly safe because they are what are termed "fire proof," and yet it is undoubtedly the case that the buildings are in many cases dangerous from the start, owing to the fact that there is a large amount of strain frequently tending to weaken and fatigue the structures in which we feel, and are perhaps, perfectly secure under ordinary conditions, but they often become really dangerous when we are least suspecting it. This feeling of security is sometimes startled by the giving way of some large structure, either from fatigue caused by overloading from its own material, or from overstraining or sudden shock. The falling in of some building at the time when it was subject to least strain, or the sudden giving way of structures subjected to fire at times when they should have stood for many hours, when all this is probably preventable, startles us and robs us of our feeling of security, and when we come to make the observations after the fact, we find that our data were unreliable, either because the material used was such as had not been contemplated in the formulæ, or for other causes which it is hoped the commission will make known and be able to prevent. The factors of safety used by engineers are taken from tables constructed many years ago by foreign engineers on materials made under entirely different processes from those now in use, and on metals manufactured abroad. We know hardly anything of these factors as applied to materials of American manufacture. We are using tables and formulæ which we are finding to our cost are only approximately reliable. It is becoming known to insurance companies that weight improperly distributed in structures is not only a source of danger against which *they* must protect themselves by charging a high premium, but that it is a source of actual money loss to the manufacturers. Instances are known where a redistribution of the weight of buildings has, with the same machinery, made an increase in output of over twenty-five per cent. possible.

There were produced in 1880, 1,218,000 tons of rails of all

kinds. Accidents from the use of rails are much less common now than they were in former years, owing to the much greater attention that is now paid to the condition of the roadbed, and it is the generally received opinion that rails need no other testing than that they receive from use in the track. Yet I have several times shown that under conditions nearly similar, one rail bore easily 80,000,000 tons of traffic, and was good for 80,000,000 tons more, while another of the same make was worn out and good for nothing, with less than that amount of traffic. It is a fact known to a few that the steel rails which are now being made are not much, if any better, than the best iron rails that were made in 1860. Those of us who are familiar with the present practice of working for the greatest possible output of the works think we are right in stating this as the reason why some of our best engineers see a possible return to iron rails in the near future, but why should not a large output of manufactured product be consistent with the greatest strength in the material? Is there not some very simple means by which the greatest product may be made of as good quality as the reduced one? These are questions which if a manufacturer answers at all he answers for himself and his neighbor, to whom the fact is unknown, or who cannot, or does not investigate, goes on producing a material, which if it is not a source of danger is at least a product inferior to what might have been made, and the world is a loser by just so much as a larger quantity of inferior material is made for use. What shall be said of that manufacturer who, knowing the defect, and the cure as well as the danger, refuses to cure it, and deliberately breaks a contract for the superior and safe material, and continues to make the inferior and perhaps dangerous one because he can sell it? The Pennsylvania Railroad is a remarkable instance of judgment and management in this matter, for they have shown and proved that the large expenditure which they make in the examination of all the materials which they use in their various structures and machines, is fully justified by the results which they have obtained. A smaller corporation, having just as much at stake, so far as its own security goes, might not be able to make these examinations, and must either wait until it can follow the precedents of the larger one, or in some other way obtain a knowledge of these results, or it must run the risk by not having them, of endangering the property

of those who are interested in them or perhaps the lives of those who use them. As the large majority of corporations are in just such conditions they must either go without or look to the government for such knowledge.

Notwithstanding an amount of study, which has certainly been large, made by private corporations, and others in the chemical, physical, and mechanical conditions under which it is best to use structural materials, we must confess that there are a large number of dark places which we do not understand in relation to them. We have now as articles of current manufacture ferro-manganese, ferro-phosphorus, and ferro-silicon. A few years ago little or nothing was known of such materials, yet it is understood definitely to-day that with the use of these materials we are able to produce metals of a quality, which without them a few years ago would have been altogether impossible. Nothing is more remarkable than the fact that within the last two or three years we have been able to use, in the manufacture of iron, phosphorus as a fuel, and the complaint is that many of the irons do not contain phosphorus enough to make it possible to get the phosphorus which the raw materials actually contain out of the manufactured product. The government, itself, for its own preservation, is interested directly in this matter. In the year 1868 a commission, of which I was fortunate enough to be a member, was appointed to examine the irons used in the forts of the United States, especially at Fortress Monroe and Fort Delaware. The results of the investigation on the ground, from the effects of 13-inch shot fired at point-blank range, were such as to convince every member of that commission that the iron was bad, and that the conditions of the contract had not been fulfilled. It was, in the first place, in the highest degree not homogeneous, defects of welding, six inches square, occurring in every direction in the plates. The result of the impact of the ball was the giving way of the plates behind in such quantities, and in such small pieces, that a mouse could scarcely have lived inside the fort. The metal was so very brittle that it was supposed to be high in phosphorus. A detail of these experiments has never been published, but the results of the investigation of the materials used, which was continued for more than a year, showed that welded plates never were homogeneous, that the iron was not in the least cold short, and was far beyond the contract-

strength, but we were not given the means to study the results of the fatigue produced by the impact of 17,000,000 foot-pounds.

Of the effects of varying proportions of phosphorus in iron, how little do we know, even though individuals have been studying it more or less for over a hundred years. I give below the partial examination of commercial products made by Prof. Akerman, of Sweden, which are valuable to-day, which five years ago would have been worthless for any purpose.

	No. 1.	No. 2.	No. 3.	No. 4.
Phosphorus, ...	4.70	7.42	10.37	15.
Sulphur, ...	0.04	0.05		
Silicon, ...	0.41	0.88	trace	
Carbon, ...	3.03	2.15		
Manganese, ...	0.18	0.25	0.11	

No. 1 looks like spiegeleisen, but is not so hard. No. 2 has a granular fracture, like ferro-manganese, is tough, but not quite so tough as white, granular charcoal pig, with three per cent. carbon free from phosphorus. No. 3 is granular, like ferro-manganese, but it is so soft and brittle that it can easily be pulverized. No. 4 looks like ferro-manganese, but is so soft that it can be easily cut with a knife. These are valuable products of manufacture made on a large scale for commercial use. Who could have predicted their use or their properties, especially of those high in phosphorus? It has been known in the various mints of the world, that the parting-pots formerly made exclusively of platinum at an enormous cost, can be advantageously replaced by iron containing a certain percentage of either phosphorus or silicon, which will resist the action of acids even better than the more expensive metal. If some means of casting ferro-silicon containing from ten to fifteen per cent. of silicon could be found, it would be an invaluable knowledge, for Dr. J. Lawrence Smith in his investigations on this metal, found that it was not soluble by aqua regia.

It was formerly supposed by all the iron manufacturers that when phosphorus was present in irons it was necessary to put in sulphur in order to neutralize it, and it was a rude shock when it was discovered that irons containing sulphur and phosphorus, were both "cold short" and "red short," but red and cold short only in the proportion of the sulphur and phos-

phorus that they contain Most of these discoveries were made either by the encouragement of the governments of the countries of the Old World, or by men educated as specialists at the expense of their governments. Why should not ours help us to become fully acquainted with our own manufactures?

There is no doubt that many of the imperfections which have produced disaster in the use of structural irons have been owing to the use of bad testing machines, and not only to this but to bad theories in the use of the good testing machines that we have. The habit of testing irons and steels on diminished areas, and then calculating that the larger section was stronger in direct proportion to the increase of area, was one of the most vicious methods that has ever been introduced into mechanical engineering. We know now from the experiments made with the United States testing machine that this is not true. We might, however, have known it years ago, and we probably should have known it had there been a distinct board to make examinations as we now propose. Nothing is more remarkable than the fact announced as the result of a series of careful tests at the Washington meeting of the Mining Engineers, in February of this year, that irons, which by contract would have been rejected if they had been tested upon small machines, were found to be entirely within the contract specifications of strength, when the work was done on the machine at Watertown, and that the contrary was also true in some cases. There is no doubt that many of the failures have been owing to defective testing. Not only are the machines themselves imperfect, but the manner of testing has in a great many instances been defective, for it has been found that the small amount of rest which an iron gets when it is allowed a few seconds of repose in the testing machine, and a new force then applied is sufficient to make the metal appear to have a much greater strength than it really has.

The law of refreshment of metals needs a large amount of careful study, for if irons may be almost instantaneously refreshed and fatigued it is quite as likely that they follow a law, which may, when its details have been ascertained, be capable of indefinite application. It is quite possible too that irons which have been really fatigued may stand for a short time and then give way, which fatigue, if it had been known

beforehand, might possibly have prevented a loss of life. We do not know, and have as yet no means of knowing, whether metals are fatigued or not at the time that they are used, but it is certain that metals which are fatigued may become refreshed, as was notably the case in some of the cannon produced in the Fort Pitt Foundry, which were condemned, but after a period of rest were found to be more than strong enough to pass inspection. We know so little about the results of impact and vibration on metals that these need very careful examination. The study of such obscure phenomena as these, which must first be produced on a large scale and then carefully investigated, can only be done by a board who shall have time and money enough to examine the phenomena in detail. If the United States Government had put in each department men of the same professional ability as have examined the properties of cast-iron for the single use of ordnance, in charge of the investigation of materials used in construction, and had been as liberal in time and in appropriations, engineers would not have been obliged to confess their ignorance, and many a disaster that has brought great distress on corporations and individuals would have been averted, and the Government would have saved more money than they spent.

It is an undoubted fact that a large part of our errors in construction are owing to the fact that the mechanical methods of ascertaining the qualities of the irons were not only in themselves defective, but that the machines were defective, so that as between two machines the results are not and cannot be comparable. In many cases, as has been elsewhere said, the factors of safety which we use are the exponents of ignorance, from the fact that the laws deduced from one set of materials are transferred to another, to which they are not applicable.

Many of our structures are undoubtedly too heavy, and are fatigued by their own weight, and would be stronger if a large amount of the material were removed from them. If we could save three per cent. of the weight of the structures, and still have them strong enough to do the work which they are called upon to do, we should save 6 00 tons of rolled iron, or 21,000 tons of the total amount of iron, steel, and cast-iron produced. It is more than probable that the saving would be much larger

than this, and yet this of itself would many times repay the expense of a commission.

We are using steam boilers, and yet we do not know much about the metal which is essential for their construction. A few corporations have ascertained that there are many points of weakness in the irons usually used for boiler plates, which can easily be avoided, and yet I believe that until within a comparatively short time, it was not possible for the boiler-makers to make specifications which would be sufficiently specific to cause an iron to be made which should be light and at the same time perfectly safe.

It is impossible to state how many defects arise from a want of proper chemical knowledge, and yet it is upon this side of the question that almost all the investigations of metals have taken place. Many manufacturers have been in the habit of thinking that what it is most necessary to avoid is having material that is "cold short," while materials of a different character might easily be worked with the greatest possible advantage. Yet it has for a long time been known that red shortness was often a question of temperature, and that a metal might weld above or below the temperature at which it was red short, and give an iron which in appearance seems thoroughly welded. But it is quite impossible even in pieces of really good quality and of moderate size to have a perfectly even weld. Many defects of welding in red short irons are doubtless due to the unequal distribution of heat, and this opens the whole question of welding, which is a source of constant anxiety and perplexity. It is, of course, best in all cases to avoid welding when that is possible, but when it is with our present knowledge not possible to avoid it, there is always a certain degree of uncertainty about any weld not actually made by fusion. Several means of detecting imperfect welds have been devised, but they are more or less impracticable. The method of detecting a weld that is imperfect beneath the surface is yet to be devised and would be a great boon. But why should we use interpenetration welds at all? I believe the day will come, and shortly too, when the defects of such welding can be made as evident to the public, as they were to the United States Commission, who examined the irons used in the armament of Fortress Monroe and Fort Delaware, in 1868, and that they will demand that severe penalties shall be

inflicted on the manufacturer who is known to use any of the old methods of interpenetration welding.

Iron and steel are, however, not the only materials used in construction. Stones, bricks, mortars, cements have been examined to some extent. We know a great deal about these materials as they are used in foreign countries, and this knowledge we apply to these materials as made and used in our own country with a moderate degree of certainty that the laws found to be true in one place will be true of the same material from a different locality; but as our climatic and commercial conditions are so different from those of Europe, we ought to have a knowledge of our own materials, and more especially of the methods of making artificial substances to be used in those districts where stones and cements must be manufactured. The whole question of refractory materials, upon which the safety of so much of our invested capital depends, is almost a virgin field. In some industries we are spending per ton of metal produced five times the amount found to be necessary elsewhere. If some of the modern iron and steel industries are ever to find a home in this country, many thousands of dollars will have to be spent in investigating this single question. We are now waiting for the results of experiments made abroad, or are using foreign materials imported at great cost, when we should be using our own.

Our knowledge of woods is extremely limited. The experiments that have been made upon them were made mostly in Europe under conditions which do not exist in this country, and so defective is our knowledge that the insurance companies have been obliged to have investigations made upon this subject for the purpose of ascertaining how the material may safely be used in the buildings they insure and be subject to the least fire risk. It seems to be apparent, from a slight study that I have made upon the subject, that as wood becomes scarcer we must have an investigation to know how it can be used economically. It is well known in Europe that woods cut in certain ways will warp, and they also know perfectly well how to prevent this warping by cutting up the log so as to make four sticks of timber from the same tree, and then cutting each stick parallel to the first cut that takes off the bark. By the ordinary method of cutting the tree either into squares or planks parallel to a given direction it is im-

possible to prevent warping. It is also known that the season of the year at which the wood is cut will not only affect its durability, but also its power to sustain a load, and that the season cracks produced by careless piling will also affect its strength. It seems to be quite possible, from a casual investigation of the subject, to construct wooden trusses and bridges which would be stronger with less weight in them than those now used, but in order to ascertain exactly what the best form is, careful investigations similar to those reported, some years ago, to the German Government should be made. The work must be done by a commission, who should feel at liberty to take the time and incur expense necessary to work up the subject.

These—wood and iron, artificial and natural stones, mortars and cements—are the materials most commonly used in construction. But there are other metals and alloys which are used in great quantity, about which we know but little. This is especially true of the copper alloys and of copper itself. Until the publication of the very able report on the copper-tin alloys by Professor R. H. Thurston, very little was known of these alloys.

I have had occasion since 1876 to make many researches, not only on copper, but upon its alloys with zinc, and I find that the material which is called copper and used as copper in the market, is of a very variable composition, and is not all equally well suited for either the manufacture of alloys or for its direct use as copper. The United States produced during the year 1880, 56,899,842 pounds of copper. Of this amount 56,655,140 pounds came from Lake Superior. The value of this product, at an average of 18½ cents per pound, is $10,526,-470.77. The total capital involved in producing this amount was $35,552,401, or $0.625 of capital invested to produce a pound of copper. In 1881 the production was 71,300,000 pounds. Of this amount the Lake Superior district produced 50,000,000 pounds; Arizona, 8,000 pounds; the other States and Territories, 13,000,000 pounds. The total amount sent abroad was 7,000,000 pounds, leaving 64,300,000 pounds consumed at home. One of the largest manufacturers in the United States estimates that of this amount 61,000,000 pounds were used in the manufacture of brass and other copper alloys.

It became necessary for me some time ago to make an investigation on some of these alloys for the cartridge companies, and after making fifty or sixty analyses and investigations of alloys in every condition, I found that it was quite possible to take metal from the same batch, which had been manufactured from the same ores in apparently the same way and put through the various machines under the same conditions, each batch of metal being apparently alike and perfectly homogeneous, and yet one cartridge manufactured from this metal would stand firing one hundred and fifty times, while another, taken from its side, would be useless after the first firing. There was no chemical difference in this material which would justify any such difference in strength. On a careful examination I found the physical conditions not only of the alloy, but of the metals in the alloy entirely different. In some cases when the alloy appeared to be perfectly good at the time it was manufactured and stood all the tests of inspection, if it was allowed to remain a short time at rest it became so brittle as to be perfectly useless. I also found that metal which stood all the tests at first, and was manufactured in large quantities, after months of rest became so brittle that it would tear like paper. After several months spent in the examination of these specimens my attention was called to the general manufacture of punched and stamped brass in the State of Connecticut, and I saw tons of refuse material, which had to go back to the melting-pot, not because the metal itself was not good, but because it had, like the cartridge metal, become fatigued in the course of manufacture. Making a careful study of the fatigues in both cases I found that they belonged to exactly the same phenomena. It was possible so to fatigue the alloy, that an unequal cold flow of the two metals took place; I have seen tons of metal in which the zinc had actually started to separate from the alloy, and this was cause of the rottenness. It is quite possible to prevent this in the manufacture, but not to cure it after it is done. The Government is equally with the private citizen interested in all these brass alloys, and an investigation which should arrive at some economical result would be of prime importance to them. As the result of these investigations, made for two different companies, I was obliged to recommend the changing of their entire plant at a very great cost. Such expenditures on

plants, which are new, are a great discouragement to the manufacturer. It means not only the loss of the capital already invested in the works, but the loss of output while the new ones are being built. The Government uses such a large amount of this very material, that they have a real interest in making the investigation, not only in their own pecuniary interest as manufacturers, but also to prevent the loss of wealth to the nation, by improper expenditures.

I was told recently, by a large manufacturer in the State of Connecticut, that it was not an uncommon thing for him to manufacture five tons of brass and put the whole of this material through a single machine for making a single part of a kerosene oil burner, and another five tons for another part, the number of parts in the burner sometimes being as high as eight or nine. Any manufacturer, or any other person who would stand by the refuse-heap of any one of these lamp-burner manufactories would see in the tons of waste material, every ounce of which might have been worked up to a profit, a source not only of private loss, but also of public misfortune, as every ounce of waste material must of necessity increase the cost of the manufacturer's article. In some cases the loss is considered as inevitable, in others investigations, often repeated and never more than partially successful, are made at many times the expense necessary for a thorough investigation. But, gentlemen, private individuals should not be expected to make these investigations. If one hundred manufacturers make the same investigations, one hundred times the amount necessary to make the investigation is expended, the country is thus the loser of ninety-nine times the amount of money necessary to do the work, which is not only a loss of wealth, but a loss of revenue from the money that might have been profitably expended in other directions. What is true of these alloys is true of all metals to a more or less great extent. The law of fatigue and refreshment is so obscure that no one but a commission, with time, money, and material at its command, can thoroughly investigate it, although it may be learned by the individual efforts of those who are willing to make these experiments 200 years hence; time under such conditions is such a factor in the question that the world of our day and of many generations which follow us may never know what these laws are. The same results could be reached by a commission

probably in a few months' experiments, and be published by them at once for our benefit, and thus anticipate an enormous expenditure both of time and capital. The whole world is interested in knowing what the proper conditions for use are for materials which enter in so large a measure into the safety and comfort of our everyday life.

Another unanswerable reason why the Government should appoint such a commission as we propose, is, that such a waste is not only a loss of time, labor, and capital, but it is a real discouragement to the investment of capital in such manufacture, and besides it increases the cost of the production of material and therefore really diminishes the wealth of the country. It is easy to say that private manufacturers have it for their interest to undertake such examinations as this, and this is true. My own professional experience is full of just such investigations, but when they are made they are the private property of those who had them made and are kept secret, in the interests of the persons who had them made, and justly so, and the sum of human knowledge is not increased and the world is no better, but is rather worse off, from having such private investigations as these constantly repeated. No manufacturer who has ever made them would communicate the results to his competitors if the result had been one which he could translate into a commercial benefit to himself, and no one would be justified in asking him to do so.

The United States is the largest single consumer of constructive materials; next come the railways, and while the United States, though most directly interested, is doing little or nothing, only a single railway corporation is making investigations for itself, which makes it what it is now, probably the best managed and the greatest railway that the world knows. What should be done is to build structures and test *them*. Let us put up a bridge, a truss, a roof and columns, put in, load, and break them, reinforce, reload, and break again. Under such conditions, I believe that but few of our present forms and shapes would continue in use, and that we should demand different qualities of metal, and be able to tell the manufacturer how to make them to his own and the consumer's advantage. We shall then come nearer to doing what the Creator, the GREAT ENGINEER, has done with all His creations. If, as the results of the work of such a commission, we could increase

the profitable use or cut down the weight of constructive materials 3 per cent., the United States would gain every year over $100,000 in each of its navy yards.

The old commission have settled once for all that the testing on a diminished area gave false results. What we know of testing on full sizes is the work of this commission, and that is extremely meagre. It is one thing to know what the individual member of a composite structure will resist, and quite another thing to know what it will do in combination with others. It is one thing to know what strain these composite members of a bridge will bear separately when new, and when fatigued what they will support under loads of certain kinds; it is quite another thing to know how the strain will act on all the composite parts put together. What we know about this subject has been learned mainly from disaster, and these disasters do not teach us what a test commission would, for the reason that disaster is always unforeseen, and there is no time to study anything but after effects, at a time when every one is horrified by loss of life, or depressed by injury to property. The discussion of how such an accident might have been prevented becomes profitable for the future, when (and in many cases this is not possible), all the facts of the case can be ascertained. It is but meagre comfort to those who feel the ruin to know that the disaster would have been prevented if certain laws of strain had been previously studied, and that their ruin was the only stimulus which could cause the investigation to be made. Science and the progress of human arts should never be advanced by disaster. We should examine all constructive material beforehand, studying each part, building and breaking the whole, and then reinforcing the weak places, building up and breaking again, until we *know*, with absolute certainty, that the duration of all those structures, upon whose safety human life and property depend, will be assured beyond peradventure. There is still another side which needs to be considered. If a building or a machine is constructed properly it will be capable of supporting or producing one hundred per cent. of work. If not, the product will be diminished more or less. Recent investigations have shown that from the imperfect construction of masonry, beams, girders, or machines, the amount may be reduced to fifty per cent., a loss of half. What are the conditions of defect? in how many cases

are the remedies applicable to structures already built? how can they be applied? No manufacturer or corporation can settle such questions. A government only can do it; and who can tell what sources of wealth may spring from such an investigation, properly conducted, in such towns as Lowell and other great manufacturing centres?

As engineers we are perfectly willing to confess our ignorance. We do not know, we cannot know, and we never shall know until the Government appoints a commission to do what we ask. When the public can once be made aware that this thing ought to be done, it will not be we who ask Congress to do it, but it will be they who *demand* it to be done.

I have thus wished to call attention to a few of these facts, —to the fact that modern metallurgy has developed processes which give physical and mechanical characteristics to the metals now being used entirely different from those which pertained to those metals at the time the factors of safety were determined; that letting alone factors, we must look for new forms of metal; that we must use the same metal to produce an entirely different result, and that we must not only look for new forms, but for new chemical combinations.

It was my privilege some years ago to announce at the Montreal meeting of the Institute of Mining Engineers a law which I believed to be entirely new—a law of fatigue and refreshment of metals. This law has assumed proportions which appear to be of much greater moment than I had any idea of at that time, for it has turned out since I have been investigating the subject of fatigue and refreshment that other engineers have found similar phenomena, and that there are, very often, kinds of fatigue of which we know but very little. I instanced, in the paper which I read at Montreal, the fact that some metals become fatigued by apparent rest, as in the case of cartridge metal, which has already been cited. This was fatigue that actually existed in the metal, but which was developed afterwards by the fact that no work was done in it. The most extraordinary instance of fatigue, however, which has come to the knowledge of engineers is in the fatigue which occurred in Fribourg on some tin rings which were exposed to constant vibration in the steeple of an old church for nearly two hundred years. These rings had been left there by accident, and had been subjected to a very slight vibration for

that length of time. When an attempt was made to remove them it was found that they were in the condition of an impalpable powder. It was supposed that they had been converted into oxide of tin, and that for some reason, either chemical or physical, the rings had oxidized thoroughly. But finally the rings were raised without disturbing the powder, and by the application of heat they were restored to the metallic form, just as strong as before. The restoration from fatigue, which occurs from rest, is better illustrated by a fact known to some of the cannon manufacturers and brought to my attention by Mr. Metcalf. It is a law of the government that any cannon which is condemned shall be immediately broken up. One of the cannon, condemned by the government officers, was not broken up. It got covered up and instead of being broken up, lay for fifteen years in the sand, and was finally dug up and tested. It was found that not only was this cannon not fatigued, but that it bore an amount of fatigue which could not be borne by any ordinary cannon. The case of fatigue where the metal is fatigued but does not show it, I have already cited to you in the case of cartridge metal, of which perhaps more than half a million cartridges were destroyed in this way in the manufactory of a single company in Connecticut.

Now, gentlemen, such things as these require to be examined. A great many of us engineers are under the impression that a metal can be used under certain conditions, and that it does not make much difference under what conditions it is used, provided it is safe for the time being. I think an investigation will prove, if made, that we are very much at sea with regard to such matters; that we need to investigate in some of these directions which I have pointed out, and in other directions as well, of which we can only know the details after this commission shall have been at work for some time, and which are undoubtedly equally important, and that a commission should be appointed by the United States, under the same conditions as the old one, and that this commission should sit as long as there is anything to be discussed in constructive material. Metals are not the only things. We ought to discuss everything relating to stone and bricks, everything relating to mortar, everything relating to wood,—in fact, everything that we use in any way whatever, in the construction of

machines, in structures that we use above ground or below ground, or that we use on the sea, ought to be examined. I had a discussion, some time ago, with a very large firm of boiler-makers, in this city, who told me that when they began to dr w specifications for the making of boilers, they found that there were no investigations that were satisfactory, that they could rely upon, for the use of boilers, even for ordinary pressures, and that they were obliged to go to the iron manufacturers, and demand certain things of them, which the iron manufacturers told them were impossible, but which seemed to them to be absolutely necessary, in order to make a boiler with ordinary safety. We think that there ought to be a commission for the examination of these, and of other things of the same nature.

The work which such a board would have to do might last almost indefinitely. The work of the old board is in the minds of most persons confined to the work of a testing-machine at Watertown. What we need, however, is not this machine alone ; we want that, but we want many other machines also, which should be devised for the purpose of doing different kinds of work under different circumstances, and we wish to have machines built for the purpose of making special tests. It is not only the structures that we are in the habit of using, but other combinations that required to be tested ; not only the materials in the form in which they are now used, but in all other possible forms ; and I am quite certain, and I think every engineer will agree with me, that before such a commission has finished its work, it will be found that the economy in weight, resulting from ascertaining the proper forms for greater strength with the same weight, would more than pay in a very short time for the whole investigation.

What is quite as necessary also, as getting at the facts, is the publication of these facts. No engineer working for his own professional reputation could be made to publish his failures, yet the failures are often more instructive than the successes, while a commission working for the purpose of producing failures would gladly publish everything, both failures and successes. Such a commission should publish everything that they do, invite comment from engineers at home and abroad, test all the theories which are advanced by engineers of sufficient reputation to entitle them to a hearing, and then publish

these results again inviting further comment, and so on. The commission then, instead of being composed of seven members, as proposed by the bill now before Congress, will be composed of all the engineers in the world who would be willing to give a sufficient amount of time and thought and take enough interest to discuss the facts; and every engineer would consider it an honor to have made a single suggestion to this commission which would help them to produce any new results.

Such a commission should in my opinion serve without pay. They should assemble at stated periods, and should direct the experiments, while those who are employed to do the actual work should be paid a reasonable salary. Any engineer of reputation and of moderate means could well afford, for the honor that he would obtain from it, to *give* the necessary time and thought involved in this work. The members of the board, however, should not be expected to do clerical work of any kind. Plenty of men could be found to do it at a small cost, certainly just as well and probably better than the members of the commission, who would then have all their time and thoughts devoted entirely, not to clerical work, but to the labors of investigation which would devolve on them. After discussing this matter at great length in Washington, the committee who had charge of the bill decided that this clerical work could best be done under the supervision of the Department of the Interior, and if they were left at liberty, as the bill anticipates, to form their own organization and do their work in their own way, without political interference, I have no doubt that the results after a very few years of the work of such a commission would add largely to the reputation of the citizens of the United States for far-sightedness and enterprise, and contribute so much to our knowledge of the real properties of constructive materials as would not only decrease the cost of living, but add so much to real and substantial comfort as to increase the average of human happiness and life.

I shall not take up the time of the society any longer. I trust that some of the other gentlemen who are to speak, will make suggestions in regard to what ought to be done and will call out facts which do not occur to us who are on the committee. The committee have decided that it is in the first place desirable that this work should be done, and in the second place that it is desirable to memorialize Congress, and

a memorial has been drawn up for circulation among those interested directly or indirectly in this subject; and then that the committee should act with a committee of the Society of Civil Engineers, and of the Institute of Mining Engineers, to endeavor to make Congress do what we think ought to be done. If the world at large knew, or if the people who are using our machines and bridges and constructive materials, knew what the actual facts were, and what the dark places are in all of these different constructive materials, we should not be obliged to memorialize Congress at all. The people would go to Congress and demand that the thing should be done, and engineers would not be allowed to do it, they would be forced to do it.

I hope that all the members of the society who are interested in this matter of tests, will take pains to see that the memorial, which will be sent to them in the course of a few days, will be signed, and signed extensively, not only by persons who use metals, but by manufacturers of every kind, because I think it will be shown that every manufacturer, if he is under a roof, has a direct interest in having all the factors of safety and all the other properties of metals re-examined and redetermined.

I have a copy of the memorial here, but I did not bring with me a copy of the bill "for testing metals and constructive materials," prepared by the joint committee. I may state that the Society of Civil Engineers appointed a committee in June last. This committee sat until January and reported to the society, and then the society decided that through its board of direction the society itself should take up the matter. They prepared a memorial to Congress, and came to Washington represented by the president and secretary. The Society of Mining Engineers was then in session in Washington, and a committee was formed, composed of eight members, who were members of the Mechanical, Mining, and Civil Engineers societies, to draw the bill now before Congress. The proceedings of the meeting in Washington, which was held for that purpose, are printed and can be obtained on application to the Secretary of the Society of Civil Engineers, or the Secretary of the Society of Mining Engineers. The action taken in Congress was to refer this to a committee, and it is now in the hands of Mr. Campbell, who is chairman of the House Committee on Manufactures. This bill has been read twice and

is before the committee. It was hoped that the bill could be passed at this session of Congress, but I think that has become hopeless, owing to the fact that there has been opposition, both latent and fully developed, to any commission whatever being appointed, under any circumstances, and the committee now call for information from engineers and others directly interested in having this bill passed. This is the condition in which the matter stands to-day, but if the bill is not passed during this session, there is very little doubt that it will be passed at the next session, if all the engineers join in doing what I think they will do when they become acquainted with the facts. And I will say here that the Civil Engineers, after talking the subject over with prominent officers of the army and some of the navy, and some of the most prominent legislators in Washington, decided that it was best to have a civil commission entirely, and not a mixed commission, to perform this duty, that at least one person on the commission should be a manufacturer of metals, that there should be at least one who was an engineer skilled in construction, and that there should be investigators, etc., and that all those who were members of the commission should receive nothing but mileage. They should have the power, however, to select and employ experts; and that the whole of the accounts of the board should be audited in the Interior Department, and the board left to do the work for which it was appointed, solely and wholly; that the work of the board should be published monthly, whenever it had any results, and results only should be given at first; and at the end of the year, after the criticism of the engineers of all the world had been invited to these results, the board could then undertake to make a report on the subject of their tests. That the board should be appointed in such a way that they should give their time and thought, but do no handwork and spend no money of their own; that the sessions of the board should be only for the purpose of directing those who are actually doing the work, and who were salaried, what to do and how to do it, and for discussing the results.

The memorial prepared by the committee, read as follows:

MEMORIAL

TO THE HONORABLE, THE SENATE AND HOUSE OF REPRESENTATIVES OF THE UNITED STATES, IN CONGRESS ASSEMBLED:

"THE undersigned, members of the AMERICAN SOCIETY OF MECHANICAL ENGINEERS, and other citizens, respectfully represent, that under the authority given by an Act of Congress, approved March 3d, 1875, the President of the United States appointed a Board, to test Iron, Steel, and other metals. That this Board made a large number of chemical, physical, and mechanical experiments, and built a testing machine which has no equal; but, that its term of office expired, by limitation of law, June 30, 1879.

"That the work of this Board was of the greatest value to all the engineering and constructive sciences, but that its term of office was so very short, that a large amount of work of vital importance both to the United States Government and to private citizens yet remains to be done.

"That it is of the greatest importance both to the consumers of all materials used in construction, as well as for the public health and safety, that these materials should be used to give the greatest amount of strength consistent with the most economical use of the metals, for which purpose it is necessary that all the materials used in construction should be tested.

"That the tests heretofore made on these materials have been for the most part made on specimens of diminished area, and under such conditions that the tests are not comparable.

"That very many of the tests, which were made the basis of the formulæ upon which engineers rely for their calculations, have been made on material manufactured under different conditions from those which exist in this country, and that this fact, together with the above-mentioned of the tests having been made on specimens of diminished area, make their conclusions doubtful.

"That the new metallurgical processes, which have been invented in the past twenty-five years, produce metals of a quality altogether dissimilar to those formerly tested, and that it is most desirable that information should be had relative to qualities of metal and materials used in construction, which were almost unknown when the former tests were made.

"That the tables of factors of safety now in general use, were constructed under conditions which no longer exist, and that it is for the interest of the United States Government—which is the largest consumer of metals and constructive materials in this country—to have these factors redetermined, as the result will undoubtedly be, that a diminished quantity of material will be used in a much safer form.

"That while it is undoubtedly for the interests of corporations and private manufacturers to make these tests, it would be against their interests to publish them when made, and that the constant repetition of the same experiments would consume a large amount of capital, but would add nothing to the general knowledge of these materials, and that the absence of this knowledge has undoubtedly caused not only much destruction of property, but also the loss of many lives.

"That the knowledge which it is desirable to obtain, can best be arrived at by the appointment by the United States Government of a Commission of skilled experts, appointed by the President with the sanction of Congress, with a sufficient amount of funds at their disposal to make experiments on members of composite structures of full size, and on the structures themselves—to determine not only what is the best quality, but also the best form in which to use the materials—whose duty it shall further be, to examine into the laws which apply to the safe use of all kinds of materials, used in constructions, and to deduce from their experiments formulæ and rules for the best and most economical use of all such materials.

"The prayer of your memorialists, therefore, is that your Honorable Body will empower the President of the United States to appoint a Commission from among experts in the manufacture and in the use and the investigation of materials used in construction, whose duty it shall be to plan and execute the needed investigations and tests upon materials used in the manufacture of machines, buildings, bridges, and other constructions, to deduce such rules from them as will lead to the greater safety of the structures, and economy in the use of the materials of which they are made.

"And your memorialists further pray that such appropriations may be made by your Honorable Body as to enable the Commission when appointed, to make the tests and experi-

ments on full-sized parts of structures, as well as on the structures themselves, and also to construct such machines as may be necessary, and also to secure the services of such skilled experts as may be necessary to carry on the experiments.

"And your memorialists will ever pray, etc."

DISCUSSION.

MR. WOODBURY: *Mr. President:* I think we all ought to favor this measure, because the results which will be obtained from the investigations proposed, will apply to the interests of us all, whether we are constructors, or whether we are owners of buildings, of bridges, of structures of any kind. In fact, it pertains to the whole range of the mechanic arts. There is an amount of failure in general construction which never becomes known, because those concerned in it are very careful not to have their methods known; and in most matters of construction we all know that we have nothing but a precedent to rely upon, and that precedent of course becomes faulty when the nature of materials changes. It is an axiom throughout physical science and the mechanic arts that it is bad policy to work from the less to the greater, because the errors are augmented, and in the structure of various materials, the strength of the whole is no multiple of the strength of the part. The tensile strength of a large bar of iron is not a direct multiple of the tensile strength of a smaller section. Even the data which we have for such purposes are largely drawn from foreign experiments with foreign materials; and those experiments which all of us have probably made, have been carried out on a very small scale. Later on we shall perhaps hear something further about this subject when Professor Lanza reads his paper on the resistance of wood columns. Wood columns are generally used in our mills in the East, where they are preferred to iron for many purposes, and yet until these experiments were made, all the formulæ which are given in the engineering books for the strength of wood columns, are based upon the compression of columns of Dantzic oak, a material not known in our markets. The experiments were made a great many years ago. The columns were very small, some two and a half inches in diameter, and were mere models. That is a question with which I have been brought face to face in certain matters, and I do

not know of any data on the strength of wood columns, such as were very readily obtained with this Watertown testing-machine; because the results which this machine furnished applied to the interests of every one. I certainly hope that the influence of this society will result in causing the testing-machine to be put to such uses as will be available to the general public.

Mr. Oberlin Smith: I am not very familiar with this subject, although I am placed on the committee. I feel that the other gentlemen who have made a study of it can say all that is necessary to be said. I can only add that I for one give my most earnest support to this whole measure. I think it is of vast importance. I should like to see the government spend a round million every year on just such work. It would return a hundred-fold. The trouble with people not engineers is that they are indifferent. They do not realize the importance of it. They do not know what this kind of work is. They do not know what the results of it are when it is done. They feel very sympathetic when a mill falls, as one did some years ago at Lawrence, on account of a defective column, and hundreds of men and women were burnt to death. There were no means of knowing whether it was strong enough or not. There was the giving way of the bridge at Ashtabula, and I may say that I escaped that accident by one train while on my wedding tour, so that it is always brought vividly before my mind whenever I think of it. Then there was the Tay Bridge disaster. When such an accident happens people sympathize with the sufferers, but they do not know enough about our profession, about the laws of physics,—you may say that the public in general haven't enough common sense—to understand what such accidents mean. The only thing we can do is to keep agitating the matter in every way; to make personal appeals to members of Congress and members of the Committee on Manufactures, who have the thing in charge. We certainly all hope it will be the means of accomplishing good. I hope that all the members of this society and of the sister societies will take the interest they ought to in the matter, and get all the signatures they can, and of the right kind. It was suggested in our committee meeting this morning that it was not of much account to have on that petition the signatures of people entirely unknown and obscure,—some of them with a mark

affixed to their names. It would be very easy to get a hundred thousand of such signatures, but they would not count for much in relation to such a subject. The petition is to be divided into columns for the names and business of the signers, and I don't know but that it would be well to state the title as well, where, for instance, a man is the president of a company. The idea is to carry that petition into Congress signed by as many prominent men as we can get,—men of weight in the community ; not only men who are known to the people as manufacturers, but men who can influence Congressmen through their general public position. I do not know that I can add anything to what has already been said on this subject. We are all familiar with the accidents that are constantly happening, and, as Professor Egleston suggests, it is not only the loss and danger that results from the breaking of a machine, but an accident of the kind damages a manufacturer's business, and in extreme cases it might ruin his reputation,—ruin it in a certain line at any rate. I call to mind an incident which happened in a shop, in my presence, which illustrates this point on a small scale. A so-called safety hoist, having differential blocks, broke with a pair of heavy grindstones. It fell down. There were a dozen or so men standing around, some of whom barely escaped being killed. Since then the men hate differential blocks. If that thing had not happened the course of affairs would have been different. Those blocks would still be used in that shop. I hope we shall hear from more of the members on this subject, as it is a very important one.

Mr. Barr: Some four or five years ago, the company of which I was then superintendent contracted for the erection of a large cotton compress. The duty required of this machine was to compress an ordinary 500 pound bale of cotton, which, as delivered by the local ginning establishments in the South, occupied nearly five feet in height. This was to be compressed to 12 or 15 inches in thickness, for reshipment North. A stipulation in the order for this press was that it should be capable of exerting a final pressure of 2000 tons on the bale. Calculations made at the time of construction showed ample power for such pressure, and, the designs having been very carefully prepared, the press was believed to be amply strong for the work. The remarks by Professor Egle-

ston and Mr. Woodbury on the strength of materials bring to my mind just now a failure in that press, which may be of interest to those who have occasion to make large castings which have to endure enormous destructive strains.

This press had two movable cast-iron platens, the upper one (which is the one in which failure occurred) was about 30 inches deep; it was operated by four 6-inch wrought-iron bolts, one at each corner. The threads were cut to the Franklin Institute standard, and were fitted with cast-iron nuts. From each corner of this platen there were diagonal ribs crossing each other in the centre; there were, also, ribs extending around the outside of the platen. Unusual care was exercised in designing this platen, as was also in the foundry, that the casting should be as free from defects as possible. Notwithstanding all the care exercised, this upper platen broke after less than two weeks' use, and under a strain considerably less than the stipulated 2000 tons. The fracture showed a defective casting, and the fault lay wholly in the design; that is to say, in making the two diagonals cross each other in the centre. Nearly every engineering textbook gives the strength of cast-iron. These values are determined usually by testing very small pieces, seldom more than 1 inch square; this is all very well, but it does not go far enough for everyday use in constructive engineering. If we take the values ascribed to these little quarter-inch specimens, or inch specimens, it would be very easy to demonstrate that we never could have applied power enough through those four bolts to break that platen; but it did break. Now with such a testing-machine as this at Watertown,—I have never seen it; I am not sure that I ever read a full description of it,—but it seems to me that if we can test the strength of large castings,—if castings can be specially made in which there will be ties crossing each other, in which there will be heavy ribs and light ribs, ribs of the same thickness and ribs of different thickness,—it seems to me that a few experiments of that kind placed on record will be worth to the engineering community at large and to manufacturers fully a hundred times more than it would ever cost the Government to make them.

Mr. Kent: It may be a matter of interest to the members of this society to know what the members of the Engineers' Society of Western Pennsylvania said on this subject last Tues-

day night. I do not think their action has been communicated officially to the other societies yet. The resolution passed by them on the subject is as follows :

WHEREAS, the American Society of Mechanical Engineers has addressed to Congress a Memorial praying for the appointment of a Commission to test Iron, Steel, and other metals, and for the appropriation of the funds necessary to defray its expenses ; and,

WHEREAS, a bill has been introduced in the House of Representatives, numbered House of Representatives 4726, for this purpose, and is now pending before the Committee on Manufactures ;

Therefore, be it Resolved, That we concur in the views expressed in said Memorial, that we heartily approve of the aims and purposes of said bill, as of the greatest importance to the public in general, and the industrial and engineering interests of the country in particular ;

That we respectfully but earnestly solicit our representatives in Congress for this district to use every effort which will accomplish the speedy enactment of said bill into law ;

That the Secretary be instructed to communicate copies of this resolution to Congressmen Erret, Bayne and Shallenberger, and to the Chairman of the House Committee on Manufactures.

It seems to me, Mr. President, that this subject has got beyond the necessity for further discussion in engineering societies. As one of our members has just said, the public are not yet educated in regard to it ; but worst of all, Congress is not yet educated on the subject. The position now is the same as where a district wants to send a good member to Congress instead of a poor member. The first thing to be done in such a case is to induce some good men in the district to use their utmost efforts to whip the ring at the primaries. If a large number of good men do not take the matter in hand, there will be no good man sent to Congress from that district. So in regard to this bill. The question is how to get this bill passed through Congress. The time is now one for action, not for argument,—we have all been argued to death on the subject for the last five or ten years. The Engineers Society of Western Pennsylvania passed this resolution unanimously. I have not the least doubt that all the engineering societies in the country will do the same. The bill should be passed. The only question is what is the best way to let members of Congress know that it is for the public good, and that the public demand such action. I leave it to the older members of the profession how to engineer members of Congress. I know nothing about it.

PROFESSOR LANZA: I am intensely interested in this discussion, especially as I have been doing some work of the character spoken of quite recently myself. I do not see how I can add anything to what has been said; but there is one point which I should like to emphasize. I refer to the importance of making our experiments under the same conditions, as nearly as possible, as are found in practice. Indeed, in many cases, in the formulæ that we use, the conditions that exist in practice have not been taken into account. It is often impossible to do this absolutely, and it is only by coming as near them as we can, and then forming our judgment upon the parts that we have ascertained, that we can do our best engineering work. As an instance, take the case of columns, which has been referred to. The load in practice is not always directly along the axis of the column, but it is frequently brought alongside, and yet none of our formulæ for columns take account of this fact.

It is recognized by the physicist that the results of experiments can safely be applied only to a small extent beyond the range in which the experiments have been made, and that they will not apply to other conditions than those under which they were made; and it seems to me that the matter of approaching as nearly as possible the conditions of practice is a matter that a commission can carry out more successfully than any private individual.

Another question which they are discussing in Germany, is whether riveted connections are not better than the American style of pin connections. Now a commission can investigate questions of this character. The question of mortising beams in building is another which has received hardly any attention whatever in the way of experiment.

I was very much pleased to hear it mentioned that the commission ought to carry out experiments, not simply with the machine, but with other means; thus, there are, at the Watertown Arsenal, immense piles of cannon-balls, which might well be used for determining the effect of a long-continued load on full-sized structures or parts of structures. I sincerely hope that such a commission may be appointed, for I do not believe that the need in which we stand of the information that will be derived from their investigation can be overestimated.

PROFESSOR THURSTON: I do not wish to let this matter pass

by without having a word to say in regard to it. It is a matter which has interested me intensely for a long time, and perhaps it would interest the members somewhat if I were to tell them more in detail of the history of the movement, what has been done, what remains to be done, and what it is hoped may be accomplished hereafter. The movement for the creation of such a Board as is now again proposed began years ago, so far as I am aware, in the Society of Civil Engineers. A committee was formed by that society, a number of years ago, to consider this subject and to draw up a series of resolutions that should lead to a discussion of the matter, and finally to the formation of some scheme of testing the materials of construction. The Board of Direction of the Society of Civil Engineers approved the matter fully, and facilitated all the efforts of the committee, and the result, finally, was that Congress was memorialized, in precisely the way we propose to memorialize it again, asking for the formation of such a commission. When these memorials had been circulated, a number of the members of the committee and several members of the society, and others interested in the movement, who were not members of the society, went to Washington and obtained an interview with the proper committee of the House. Several of us represented the case as well as we could, and we were given a reasonable hearing. In fact they gave us much more time than they had proposed to allow us, and listened with a good deal of interest to our representations. And when the gentlemen retired, and the committee were left to their deliberations, they discussed the matter for a short time, and presently one of their members came out and asked if $20,000 would be enough to do the work proposed. He was informed that $20,000 would make a beginning. He went back to the committee, and after a time there was inserted in the appropriation bill a provision for the application of $75,000 to the work. After some vicissitudes, such as always occur in legislation, it finally went through Congress, and a Board was appointed, and the appropriation of $75,000 was placed at its disposal.

But before this time, Colonel Laidley, commanding then and still the Watertown Arsenal, had been desirous of obtaining a good testing-machine for doing ordnance work, and the chief of the Bureau had succeeded in getting an appropriation of $25,000 for the building of a machine, and a contract had been

entered into with Mr. Emery, the inventor of the one finally built, for the construction of such an apparatus. When the Board was formed, that contract had lapsed, or was about to lapse, but immediately on the creation of the Board the plans of the machine were laid before it. They were examined by a sub-committee of the Board and thoroughly approved, and instructions were given to the inventor to prepare a contract. At the same time there appeared before the Board Mr. Charles Emery with a modification, or another form of machine, and it was considered desirable to combine the two forms; not that we doubted the efficiency in any sense, or the accuracy or sensitiveness of Mr. Albert H. Emery's machine, but the Board wanted also to have on hand something that it could use either in case of the disablement of the Albert H. Emery portion, or in case it should prove that it might take longer to construct the machine than the contract term. The contract was made and was to be fulfilled in four months. It was done in four years. In the meantime the Board was expecting this machine to be completed, and ready for work; at almost any time from month to month, it hoped to hear that it was so far along that it could be used. But the construction was retarded, and the Board never did succeed in using it at all. As soon as it became evident, in fact before it became certain, that we were likely to be detained, a plan of investigation was laid down which was very complete. The members consulted directly and indirectly with all those people, throughout the country, who were likely to have an interest in the matter, as to the best method of doing the work, and we received communications from leading engineers, from departments of the Government, and from other quarters, that led to the planning of a system of investigation that was thought, at the time, to be as reasonable as complete.

The extent of the field to be covered by this investigation may be judged by the details which are given as to the several minor investigations. One matter,—I have them in alphabetical order,—that seemed to be important, was the consideration of the subject of the abrasion and wear of metals in actual use. One section of the Board was instructed to examine and report upon the abrasion and wear of railway wheels, axles, rails, and other materials, under the conditions of actual use. Another subject, brought up by the Army and

Navy members of the Board, was the study of the kinds of metal best adapted for the construction of armor-plate, and the conditions under which armor-plate could be most thoroughly relied upon to resist the impact of shot. That investigation was confided to members of the Board under the chairmanship of General Gilmore. On that investigation some little work was done as on the preceding, but not enough to justify a report from the committee, and nothing has appeared, or will appear, in the Report of the Board in relation to such matters. They represent incomplete work.

A Committee on Chemical Research was instructed "to plan and conduct investigations of the mutual relations of the chemical and mechanical properties of metals." Up to that time, so far as I am aware, no tests of metals were ever made in which the metal tested had been identified by its own peculiar properties. It had been stated, by persons who had tested metals before, that in breaking down a bar or girder, made by a certain manufacturer, certain densities were found and certain resistances to fracture were measured, but nothing was said as to the character of the metal. We simply had to infer that, if it were made by a certain manufacturer, it was of excellent quality, or, if made by somebody else, it was of poor quality. No examination was made of its physical structure. And this Committee on Chemical Research was expected to examine and report on the mutual relations of the chemical and mechanical properties of metals. That is, to test pieces of metal; determine what were their mechanical properties; what was their resistance to strains; what would be the amount of stretch under certain conditions; under what conditions they passed the elastic limit; where that limit was; what resistance might be met with in case they were attacked by impact. And having done that, a chemical analysis was to be made, and a physical examination of the metal, so that when the work was done, we should say, not that a metal, made by a certain company, exhibited these properties, but that a metal having 98 per cent. of iron, and a fraction of 1 per cent. of carbon, and the balance in other impurities, exhibited a certain density; had a certain amount of stretch, and certain other properties and qualifications that were exactly specified. When an investigation is made in that way, of course you know precisely what to infer, and up to the time when that committee com-

menced its work, no such thing had ever been done, so far as I know. It was the rule from the beginning never to say that a piece of metal, made by the Phœnix Company, or some other company, exhibited a certain density; but to say that metal having a certain composition determined by careful chemical analysis, and having a certain structure, gave certain results. And when the results obtained in all these directions of research came to be placed upon record, it was a record for all time. That this was one of the investigations planned and entered upon, and the results, so far as any were accomplished, will be found in the second volume of the Report of the Board, which is now in press. I have already sent to the printer the complete volume made up with plates inserted with directions for the binder. So that it will be ready just as soon as the printer and binder can get through with work that is pushing them during the session of Congress. I doubt if it will be completed until after Congress adjourns. A new edition is being issued of the first volume.

Another investigation, which was planned, and to a certain extent carried out, was upon chains and wire ropes. The committee was instructed to determine the character of iron best adapted for chain cable, the best form and proportions of link, and the qualities of metal used in the manufacture of iron and steel wire rope. That committee took up its work, and investigated one section of it with some degree of thoroughness. The manufacture of chain cables was studied in all its details, from the point at which the cast iron entered the puddling furnace to the point at which it became a finished chain, and the result of that investigation was to discover some very important matters bearing upon the value of chain cables; their strength, their density, and their liability to break under the surging of a ship at sea. And it was found incidentally that the density of a piece was affected very greatly, not simply by its strength, but by the amount of work done upon it in the rolling-mill; and to my mind the fact brought out by that committee, that iron can be made of as high tenacity in large sections as in small, within certain limits, was one of the most important matters brought out by the board. It was found that one-inch rod could be got having a certain strength, and from the same metal bars of two inches diameter could be made having pretty nearly equal

tenacity. Previously iron had been rolled in the mills from piles of certain convenient sizes. Small sizes of merchant bar are now rolled from piles relatively larger than the larger sizes. Consequently there is more work done, and higher tenacity, greater uniformity, and better quality generally are obtained. This investigation showed that these same qualities could be obtained in the same iron in larger sections by taking the precaution to do the same amount of work there.

That investigation was published in full in the first volume. It will appear in the edition about to be published, revised, and somewhat extended, supplemented by a report on the later work of the Board, and with a complete revision of the earlier results.

Another matter which it was proposed to investigate was the corrosion of metals. The gentlemen to whom it was intrusted were instructed to investigate the subject under the conditions of actual use; how exposure to moist or dry air would affect the corrosion of metals; how the presence of other metals in contact with them would affect the rapidity of the corrosion of such metals. That investigation was simply planned, but never carried out. The Board went out of existence before it made fairly a beginning. The committee did as other committees had done; it sent out circulars to everybody to whom it thought the matter would be of interest, or from whom it thought it could get information, and to engineering societies at home and abroad. Wherever information could probably be obtained relating to such matters it was sought, and it was supposed that in the course of time a large accumulation of facts would be gathered from other sources, which would be a valuable part of the report of that section of the Board.

Another investigation was to determine the effects of variations of temperature upon the strength and other qualities of iron, steel, and other metals. One of the best series of experiments ever made on this subject was made by a committee of the Franklin Institute, of which we are the guests, some forty-five years ago, and you will find the report of that committee in the Journal of the Franklin Institute for about 1836 or 1837; and since that time, so far as I know, nothing like an extensive work has been done. This Board proposed to take up that matter and make that investigation a very complete one, and in the meantime to seek information from other bodies and

from other individuals, and from various sources wherever it could be found, and so compile something that should be really valuable. That is an investigation that remains yet to be carried out.

Another committee was instructed to arrange and conduct experiments to determine the laws of resistance of beams, girders, and columns to change of form and to fracture. That committee got about its work rather late. Other work stood in the way; and about the time the Board saw its last days approaching that committee did get some work done, and you will find the results, valuable so far as they go, published in the second volume of the Report of the Board. That committee should have had at least a year to pursue that investigation. In connection with its own investigations, it would have studied up the work done at home and abroad. A great deal of work has been done on the subject. You will find in the transactions and records of foreign societies a vast amount of extremely valuable matter on this subject. This is a matter that will require the study and work of the new Board for probably several years. It is a matter of such great importance, of such supreme interest, that as long as engineers continue to work with these materials of construction, they will be compelled to revise and to continue their experiments.

An investigation was to be made of the properties of malleable iron. The committee was instructed to report upon the mechanical and physical properties of wrought iron as a material of construction, not in any special form, but the material itself. It was proposed to take all the kinds of wrought iron in our own and foreign markets, and find out what exactly were the properties, and how, with variations of composition, those properties themselves varied. There is an immense field of investigation there, simple as the matter seems. The gradation that is now going on from wrought iron into steel, and through the mild steels into tool steels, is one that is like the fading of light into dark; and this investigation would have gone on and dovetailed into the investigations on steel made by other sections of the Board. That special investigation had not been made. Plans were made, very completely I presume, in this case, and the plan of campaign having been formed, it would have been a much less difficult matter to have gone on from that point, and to have made the investigation and com-

pleted it, than it will be now, when we must lose all this preliminary work and begin right at the foundation.

Another investigation was of exactly the same character in regard to cast iron, the mechanical and physical properties of cast iron as a structural material. You will see, as I go on, how all these matters dovetail into each other and finally form one complete whole. I do not know of any department of the study of engineering materials that is not brought in here.

Another study was that of metallic alloys. The instructions to the committee were, "to assume charge of a series of experiments on the characteristics of alloys, and an investigation of the laws of combination." That investigation was carried out more completely and more thoroughly, and so far as the first investigation was proposed to be carried out, more satisfactorily than either of the others. The plan of operation was very complete, and the facilities for carrying it out were given by the Board. The means were at our disposal. We required small testing-machines, not large ones; and the consequence was, we were able to put two or three men at work, men who took an interest in the subject—skilled experimenters, intelligent, educated, and interested. The investigation went on, and was completed as a preliminary investigation. You will find the records of that investigation complete in the first volume of the Report of the Board, so far as the investigation covered the study of the copper and tin alloys You will find in the second volume of the Report, about to be issued, the records of the tests of copper, tin and zinc alloys. But the committee was stopped in the midst of its labors. It had completed a preliminary research on copper alloys, and it had made experiments on the other sections of its work, when the Board died, and the deductions to be drawn from the results obtained can only be drawn by studying the records as printed. The committee to whom it was intrusted had not time to work up the matter and put it into a concise form, as it should have been allowed to do. However, I have inserted in the second volume of the Report some of my own papers, in which I detailed some minor matters of investigation, and also gave a kind of summary of the results of the work, for presentation to the American Society of Civil Engineers. That society, as being the parent of the movement, seemed to be entitled to all the special information that could be given, and where any-

thing striking came out, it was put into the form of a paper and presented to that society, and is printed as a sort of appendix in the second volume of the Report of the Board. But a thorough, carefully prepared report has not been made.

Another interesting direction of study was that of orthogonal simultaneous strains; that is, strains produced in a metal simultaneously, but in rectangular directions. It may prove to be an exceedingly important direction of investigation. It is entirely untouched so far as I am aware; and when we laid down that matter on our programme we were unaware of any experiments at all ever having been made. In every structure you will find that these strains occur. I think nobody knows as yet what is the difference in the resisting power produced by a change of direction of the strains, or the result produced by simultaneous strains in different directions. You will find theoretical treatments of the case. Rankine gives a very beautiful one. But they are unsatisfactory simply because they are not corroborated by experience, and no engineer of experience and good sense would be governed by simple theoretical treatment until it had been fully corroborated by careful investigation and research. That remains to be done. You will find not a word about it in the Report of the Board.

Another line of study was the physical phenomena occurring during these tests of materials. It was proposed to make a special investigation of the physical phenomena accompanying the distortion and rupture of materials. It was going into a field entirely dark. Electrical forces arise, magnetic changes occur; anything else may occur; we do not know what occurs there. It was hoped that something would give us a clue to results in that direction. It may be that it might have revealed much; but nothing was done.

An investigation upon the effects of re-heating and re-rolling was proposed. The committee was instructed "to observe and to experiment upon the effects of re-heating and re-rolling, or otherwise re-working; of hammering, as compared with rolling, and of annealing the metals." To a certain extent that investigation was carried out, and incidentally by the committee on chain-cables: and you will find considerable very valuable matter in their report bearing on this point. In fact that committee accomplished more in side directions than either of the others. This is one of the things from which they did get

something. The fact that re-heating and re-rolling and re-working metals in various ways modifies their properties to a very important degree has been very long known. In fact we know that this change, included in all the phenomena of subsequent action in the manufacture of the iron, occurs even in the laying of a piece of iron out in the weather. I have lying among my specimens somewhere a piece of a rail laid down fifty years ago on the old Camden and Amboy Railroad, a rail rolled in Great Britain and sent to this country. That was, when it came here, a hot-short and a cold-short piece of metal. It lay on the track there for forty odd years when I got hold of it, and it appears to be still a good piece of metal, and some of it has been rolled into merchant bar and has made an excellent material. The effects of re-heating and re-rolling are very marked on wrought iron, and the effects of remelting on cast iron have been investigated by Rodman and others and shown to be important. That work remains to be done by the committee about to be formed.

Another matter to be studied was the constitution and qualities of steels produced by the modern processes. During the last twenty years have been brought into use many structural materials of an entirely different quality from what existed before that time. Bessemer and Siemens have given us metals that are gradually putting out of use the old metals. That committee were to investigate especially the qualities of these new materials. That was the direction for the work of that committee, and it was barely entered upon. You will find comparatively little in the Report about it, although you will find that the reports on some other subjects throw a considerable amount of light on this. But it is one of the most important of all these directions of investigation, and one upon which least is done.

Finally a committee was proposed to study the steels used for tools. You see the whole field was covered by these committees. An investigation carried on in this way should have been thoroughly complete. It would have occupied years, but the time would have been well spent, and the money expended would have been returned a thousand times over. There were a good many other directions of investigation opening to us, and some of immense importance. For example, one which does not appear here at all was the resistance of tubes and

flues to collapse. Gentlemen engaged in marine engineering and members of the Navy Department, especially, impressed on us the necessity of making investigations in regard to the resistance of flues. There is not a man who can tell you what is probably the resistance of a 42-inch flue made of $\frac{7}{8}$-inch iron. Nobody knows how that resistance varies with variation in length or thickness or diameter. Fairbairn's experiments were made on a comparatively small number of flues. He knew nothing at that time of welded flues. Here is a matter on which hundreds of lives are constantly depending and on which we know almost nothing. We simply know this, that these big flues, made of this thick metal, have not the strength that Fairbairn's formulæ indicate they should have. That is one of the things, then, that we did not even plan researches in regard to.

And so the Board laid out a plan of campaign such as I have sketched, and of course talked over a good many other things I am not able to speak of now. And when this Board had so planned its work; when it had begun its work; when its members had spent days and weeks, and months of time, giving health, strength, and almost life in some cases, and when they had just reached a point where work could have been done satisfactorily, the Board died, and that is the condition of the matter to-day.

Now the thing that ought to be done, in my opinion, is simply to bring that Board back to life; bring back its plan of campaign; bring back into existence all its methods of investigation. It had made a good start, and all that it did certainly ought not to be lost. If that cannot be done, let us get at the work again the best way we can. If we must go back to the beginning, let us do so; but at any rate let us get at the work once more and get more results. If you will take the trouble to look through these volumes, containing perhaps a thousand pages, of the work done by the Board, it will give you a very faint idea of what could be done by the Board properly supported by public sentiment, as well as by proper appropriations, and pursuing its work without embarrassment for a series of years. It should be done at once. The importance of the matter exceeds the importance of any measure of legislation now before Congress. Important as it is that we should have a new navy, I think the importance of a re-establish-

ment of this Board is vastly greater. I do not want to talk all the afternoon about this thing, and I have probably said enough to show you my interest in the matter, and what ought to be the interest of every man in the profession. I can speak of this matter without any self-interest, because it is a matter I do not feel I am likely to go into myself at all, and I can without the slightest embarrassment urge upon every member of the society that he endeavor with his utmost strength to bring about the formation of this Board.

MR. LE VAN: I would like to say that with cast iron, the form has as much to do with the strength of the structure as the material itself. The reason I mention that, is that Mr. Barr referred to a platen that he had made. I am satisfied that the internal strains of that platen itself were such that it was ready to break. Every projection that is put upon a column reduces its normal strength. I would like to ask whether form in cast-iron structures was to be taken into consideration.

PROFESSOR EGLESTON: Yes. It is one of the things to be taken into consideration.

MR. LE VAN: It seems of late years that engineers try to introduce all sorts of architectural designs in building machinery, very much to its detriment in regard to strength.

MR. BARR: After this platen was broken, of course we had to furnish a new one, and as the cotton press was built and in place, the new platen could not exceed in size the one that it was to replace; so that instead of running these two lines diagonally across the platen, from bolt to bolt, we carried them straight across lengthwise and put a heavier plate underneath, and then we put other plates in the centre. Now I believe that if instead of running those two pieces diagonally, as we did, if they had been run to a circle, it perhaps would have been better. Suppose in the centre we had made a cylinder, say twelve inches in diameter and run these diagonal pieces into that, leaving an opening in the centre and then going to the other side, it would have made a much stronger form; but that only opens the question again as to testing materials in actual sizes and conditions.

MR. PARTRIDGE: I presume there is not a man in our society who is not only thoroughly convinced of the necessity of the Board, but is heartily in favor of every effort that can be made

to get another commission in operation. The question arises now, what can we do individually? The joint committees and the local ones are doing all they can. In our form of government, we have to work in a very different manner from what would be necessary in the Old World. It will not answer simply to attempt to move it by taking hold of the heads of departments. We must commence with the constituencies, and every man here to-day can do effective work for the establishment of the commission by influencing the large manufacturers, the most influential in his district or the most influential men among his acquaintances. I understand that Professor Egleston has, or will shortly have, petitions to be signed. Now if every man among us will get copies of the petition, visit the manufacturers with whom he is acquainted, visit as many persons who are influential with his Congressman as he may be able; get their signatures, whether they are manufacturers or simply influential men in the district, and then send those signatures to Professor Egleston, he will be doing good work. When we have the public generally educated to the advantages of this—even if they are, as you might say, ignorantly educated—if they simply are in favor of it, because you tell them that it is the right thing, and they believe you—when we have got that, there will be little difficulty not only in getting the commission, but in keeping it alive.

MR. METCALF: I did not come here this afternoon to say anything. I came more to meet friends than anything else. But in reference to one or two matters that have come up—the platens that were spoken of—matters of that kind; also matters that the President mentioned, I would like to say that I have seen very large castings laid out of doors on a summer day and heated up by the sun, and then a thunder-shower would come and they would be broken through in the middle after the shower was over. I have seen large castings made of the finest iron that could be procured anywhere without reference to cost, split from one end to the other simply by a very small stream of water from a waste-pipe—splitting the iron without any reference to lines of resistance or anything else. It must be perfectly patent to every engineer here and every manufacturer, that it is utterly impossible for any private corporation or association to undertake to lay down the laws that govern cases of that kind. It must be done by the Government, for it

is going to cost an immense sum of money to do it in such a way that it will be of any value at all.

In regard to steel, the portrait of our lamented friend reminds me that he spent many hours of his time with me in regard to preparing a series of tests of steel. The committee, which spent a good deal of time on that work, started out to get an iron manufactured from a well-known ore; procured samples of the ore; had it analyzed, and the iron manufactured by the Catalan process. That was analyzed carefully. The proportions of carbon were regularly increased up to 1½ per cent. Phosphates of iron were made, and the iron was tested with phosphorus from one one-hundredth of one per cent. up to one half of one per cent. Sulphides of iron were made, and the iron tested with them. An attempt was made to apply a similar system to the manufacture of iron, but that failed. And these samples were sent to this testing Board, and it was supposed that something would be obtained from all that work. The report of the chemist and the tester and the Board was that there was no relation whatever between the efforts that had been made to manufacture this steel and the final results obtained. That does not prove that the experiments were not made with the utmost care both by the manufacturers and by the Board, but it proved that one set of experiments has no value whatever when you come to lay down a law of strains or resistance of strains. And that matter of working out the alloys that can be found in steels can never be determined without thousands of experiments, and it is that simple reason that was the cause why every single engineer in this country and Europe who had occasion to criticise Dr. Dudley's experiments, criticised them unfavorably; because there were not a sufficient number of experiments made to prove the results. We all know the immense amount of work that has been done. We all know what we can gather here and there, out of the technical literature of this country and other countries, and yet the simple fact is to-day that the very best engineers in this country are going from one manufacturer to another to try to find out what they may use and what they may not use. There is not an engineer in this country that I have met, who says that he knows what he can get for a certain material, but he knows what he requires as learned from his experience and the experience of others. For these reasons I am firmly convinced that the only

way that engineers can ever get the information they need is through a public commission, maintained by the Government. And another reason, which I had occasion to mention before, and which I will repeat here, is the fact that it is impossible for engineers in their ordinary practice to get at the root of the matter. As you all know perfectly well, if an engineer goes to a manufacturer to obtain a certain lot of material of a certain brand, he will test it, he will know what test it will endure. But if he goes to the manufacturer and asks him how that material was made, and what it was made of, and how it was worked, the manufacturer will tell him very politely, but still in a way that he will understand perfectly well, that it is none of his business.

And the manufacturer is right. He is making a certain material which is known by its brand in the market, and has a certain value, and he feels that if he publishes his whole mode of manufacture that others will use all that they can of it, very possibly to his disadvantage. Now a Government Board can go to the same manufacturer and can say to him, "We want to get at certain results. We want to know the effect of reheating; the effect of working from different-sized piles. Now if you will take a certain raw material and give us samples to analyze, and give us the whole history of the manufacture, we will give you the physical and chemical results of it." No manufacturer will object to that. And in that way only is it possible for engineers to get at any information which will enable them to specify the proper modes of working these materials; and all of us who have been engaged in the manufacture of iron and steel certainly know that the mode in which these materials are manufactured and manipulated, controls more than perhaps the chemistry of them, the results that the engineer can obtain from them.

LXIII.

A STANDARD GAUGE SYSTEM.

BY

GEORGE M. BOND, HARTFORD, CONN.

In a paper presented at the May meeting of the society last year, a statement, or "report of progress" was submitted, showing the method adopted by the Pratt and Whitney Company, of Hartford, Conn., by which the question of practically establishing a standard for size gauges was to be scientifically determined, accurately subdividing the Imperial yard into feet and inches and fractional parts of an inch, and describing briefly the extent to which was carried the scientific research found absolutely necessary for such an undertaking; it remains now to present to the consideration of those who may be interested, a statement of the results proceeding from the practical application of all the thorough, conscientious investigation of Professor Rogers, of Harvard College Observatory, whose invaluable experience and professional services, in obtaining for the company the transfer and subsequent subdivision of the British yard, gave the foundation for what has been accomplished, enabling the company to feel warranted in earnestly inviting an inspection of the means now available for the production of standard sizes, and asking for it the indorsement of the engineering profession, should it be found worthy of such necessary support.

The comparator referred to in the previous paper, has been placed in position upon brick piers in a room outside the main building, erected especially for it, and is comparatively free from the jar and tremor of the machinery, even unaffected by the jar of passing trains, the tracks of the New York, New Haven and Hartford, and of the New York and New England Railroads being quite near, the rigidity of the instrument and the excellent workmanship in its construction preventing any perceptible vibration during an observation, even when the high-power microscopes, magnifying 150 diameters, are used.

The illumination required in using these microscopes is per-

fectly attained by reflection, using a plate-glass mirror placed outside of the window of the comparing room, at an inclination of 45 degrees, giving clear diffused light, cloudy weather even improving the general effect, as the light is then whiter than that reflected from a clear blue sky, and the lines on the standard bar, as seen through the medium of the Tolles' illuminating prisms with which the objectives are fitted, are clearly and sharply defined at any time during daylight, and in any position of the microscope plate; by thus avoiding the use of artificial light and consequent effect of a variable temperature, far more satisfactory results are obtained.

The investigation for the determination of the necessary corrections for errors due to horizontal or vertical curvature of the path of the microscope plate, has shown conclusively the unexcelled workmanship in the construction of the comparator; as an instance of how slight these errors really are, it was found after repeated observations, the means being carefully collated, that the horizontal curvature, *i. e.*, the bending sidewise of the cylindrical guides or ways upon which the microscope plate slides, at the part investigated, was that having a radius of *eleven miles*, and a consequent correction to be applied of about one ten-thousandth of an inch in eighteen inches, the latter distance referring to the position of the measured standard when placed either side of the line of motion of the centre of the microscope plate, moving between fixed stops, and which is the constant quantity to which is referred the subdivisions of the standard bar; as the microscope is usually within one inch, rarely over two and a half, from the centre line of the stops or caliper jaws between which the end measure pieces or the cylindrical gauges are placed, this correction evidently becomes too small to be applied practically, within the limit of a six-inch gauge; for a foot or a yard it would become necessary, as the variation of the chords of the subtended arcs then becomes quite perceptible. The errors due to inequality of temperature in the standard steel bar and the hardened steel end-measure gauges must be carefully guarded against, the latter effect being far more important, practically, and often very misleading. In the case of a four-inch hardened steel end-measure gauge experimented upon, the coefficient of expansion being nearly one one-hundred thousandth of its length, one degree of change of temperature

from that maintained in the reference bar introduces an error of about one twenty-five thousandth of an inch in the total length, and hence, as a change or inequality of five or even ten degrees might be easily overlooked, the four-inch gauge would be found to be from one five-thousandth ($\frac{1}{5000}$) to one twenty-five-hundredth ($\frac{1}{2500}$) of an inch too short, when equality of temperature is restored, when it is asserted that an actual variation of so minute a quantity as *one thirty-thousandth* of an inch, and even less, can be readily detected by any tool-maker familiar with the use of an ordinary micrometer or a close gauge, the importance of keeping *within* this limit is apparent,—of course, this shortening effect is not so marked in smaller sizes, still the ratio is the same, and this error must be carefully avoided.

The subdivisions upon the six-inch hardened steel standard bar have been carefully investigated upon the new comparator, to determine how nearly these inch spaces equal each other, the total length of the four inches which are ruled upon this six-inch bar being *exactly standard* at 62 degrees Fahrenheit, according to the preliminary report of Professor Rogers, received December 1st, 1881, and in this report, the results obtained by him, determining this relation of the inch spaces to each other, were found to agree closely with the results obtained by me, as the following comparison will show, these minute corrections being necessary in accurately determining the subdivisions of the Imperial yard, which they represent:

Corrections.	Prof. Rogers' Report.	Results obtained.
Total 1 inch, *add*, . .	0.000008	0.000008 ($\frac{1}{3}\frac{1}{6}$ yard.)
Total 2 inches, *subtract*, . .	0.000026	0.000027 ($\frac{1}{1}\frac{1}{8}$ ")
Total 3 inches, *subtract*, . .	0.000005	0.000006 ($\frac{1}{2}\frac{1}{1}$ ")
Total 4 inches, ...	correct	correct ($\frac{1}{9}$ ")

(The errors being counted from the first line.)

The results given in the last column are the *means* of a number of observations, taken at different times and under various conditions of temperature, etc., and cover a period of about four weeks, the final results having been obtained December 31st.

The value of the divisions of the micrometer employed was carefully determined in order to reduce them to the same unit used by Professor Rogers, and was found, using the microscope marked "B." to equal $\frac{1}{58\frac{1}{6}00}$ of an inch (0.000016 nearly).

When it is considered that the two results were obtained under different conditions, using different microscopes, and with comparators differing in construction, the correctness of the *principle* upon which the comparison is founded, certainly needs no other proof.

The method of obtaining this relation of the separate inches upon the six-inch standard, was referred to in the former paper, and is that of comparing each inch with a constant distance moved over by the microscope plate between fixed stops, a constant pressure of contact being obtained by the use of electro-magnets, the separate inch spaces being thus referred to an *invariable* quantity or distance, and their relation to each other consequently determined.

To explain more fully this operation, the method adopted is as follows: A series of readings are taken at the zero or initial line of the first inch space, using the micrometer referred to, the microscope plate being held firmly against the fixed stop by the electro magnet; the microscope then moves with the sliding plate until the latter is in contact with the other fixed stop, and held by the electro-magnet, the plate having moved as nearly an inch as it may conveniently be done,—generally a little more than an inch, in order to have the *sign* of the reading always the same,—from three to five readings of the micrometer are then taken at each position of the microscope, and the order reversed, to eliminate possible error; the first inch is thus compared with a fixed quantity, and the same operation repeated for the remaining inch spaces.

The difference between the distance moved by the microscope plate and the distance between the defining lines representing inches, is found by subtracting the *means* of the readings obtained, and thus eliminating the possible error of any single observation.

The following is a series of micrometer readings, and comprises the means of all the observations by which the corrections of the separate inches were obtained, illustrating the system adopted, and which has been used invariably by Professor Rogers in his investigations of the subdivisions of the yard and meter bars, now in the possession of the Pratt and Whitney Company.

COMPARISON OF INCHES.

	L.	R.	L.	R.	
	58.1	65.8	58.0	65.5	
1st inch, . . .	58.6	66.0	58.1	65.8	Reverse
	58.5	65.4	58.0	65.8	order.
Mean, . . .	58.4	65.7	58.0	65.7	
	58.0	65.7			
Mean, ...	58.2	65.7			

R − L = + 7.5 divisions of micrometer.

	L.	R.	L.	R.	
	56.2	65.8	55.4	65.4	
2d inch, . . .	55.6	65.8	56.0	65.4	Reverse
	56.2	66.0	55.4	66.0	order.
Mean, ...	56.0	65.8	55.6	65.6	
	55.6	65.6			
Mean, ...	55.8	65.7			

R − L = + 9.9

	L.	R.	L.	R.
	55.0	63.0	57.0	63.0
3d inch, . . .	55.8	63.0	57.0	63.5
	55.7	63.6	57.0	62.8
Mean, ...	55.5	63.2	57.0	63.1
	57.0	63.1		
Mean, ...	56.3	63.1		

R − L = + 6.8

	L.	R.	L.	R.
	57.4	64.3	56.0	64.2
4th inch, . . .	57.8	64.8	56.1	64.5
	57.8	64.8	56.8	64.5
Mean, ...	57.6	64.6	56.3	64.4
	56.3	64.4		
Mean, ...	56.9	64.5		

R − L = + 7.6

Correction Σ	
+ 7.5 + 0.45 + 0.45	= correction for first inch.
+ 9.9 − 1.95 − 1.50	= correction for first 2 inches.
+ 6.8 + 1.15 − 0.35	= correction for first 3 inches.
+ 7.6 + 0.35 ± 0.00	= correction for 4 total inches
Mean + 7.95	

The differences of the observed inch spaces with respect to the constant quantity obtained by the motion of the microscope plates, are added and their means taken, from which the

corrections are determined with the proper signs, to determine the total error counting from the first line. These corrections are added, the final result being evidently zero, the column under "Σ" showing this algebraic sum.

It may be appropriate here to state that the six-inch bar upon which these four-inch spaces are traced, is a standard which is, without doubt, the only hardened steel *line-measure* bar in existence which is exactly one-ninth part of the Imperial yard at 62 degrees Fahrenheit, and Professor Rogers guarantees it as such in his report, before referred to.

In order to apply these subdivisions, which include all sizes, from one-sixteenth of an inch to four inches, varying by sixteenths, to a practical form, fixtures have been provided and are in constant use, for reducing to *end* measure the distances thus accurately spaced; a caliper attachment has also lately been added, from plans proposed by Professor Rogers, by which the diameter of existing cylindrical gauges, as well as the length of end-measure pieces from one-sixteenth of an inch to six inches may be tested with the same precision that characterizes the investigation of the linear spacing of the standard bar, also providing means for a rigid inspection of finished gauges before they leave the works, thereby insuring uniformity.

To illustrate how nearly alike two pieces may be made, two standard inch end-measure gauges were worked down under the microscope, independently of each other, using the lines upon the ruled standard reference bar and the fixture referred to, which, when compared with each other by the most careful tests, using close or "snap" gauges, and tested thus by toolmakers experienced in work requiring the utmost practical precision, neither piece could be singled out as the larger, the effect of unequal expansion caused by temperature being avoided during the test. Under the microscope, both pieces were found to be exactly alike by a *single* observation, while the comparison by a series of readings of the two pieces showed a mean difference of one-tenth of a division of the micrometer, and when it is remembered that one division has a value of only $\frac{1}{5\,8\,5\,0\,0}$th of an inch, the duplication, it may be assured, is certainly satisfactory, and is clearly within a practical, if not a theoretical limit of accuracy.

Having thus the means for closely reproducing established sizes, and no possible wear occurring to the bar from which

these sizes are taken, the accurate duplication becomes a comparatively simple operation.

In order to produce standard work within the limit of a yard or a meter, there has been furnished by Professor Rogers, two steel yard and meter bars, referred to in the previous paper, one of these bars tempered, the other being left soft, but having hardened steel plugs, which are adjustable, for the purpose of bringing the surfaces into focus under the microscope; upon these hardened plugs the lines are ruled, both bars having line and end measure, thus providing means for testing the accuracy of the pitch of screw threads of any desired length, and for standard length gauges up to thirty-six inches, or to a meter.

The coefficient of expansion has been determined for each by Professor Rogers with an exactness never before attained, as stated in his report, and also the relation, at 62° (F.), between these steel bars and the two bronze standards, both of which are line measure (the latter are described in the previous paper referred to), so that gauges of any size may be made almost independently of temperature, other than the care required in keeping this condition as nearly uniform as possible for both the reference and the measured bar during the time of the transfer, or the determination after having been transferred.

The subject of accurately producing standard leading screws is receiving its share of attention, and those who use micrometers will readily understand its bearing upon the precision with which they may be made, and how unsatisfactory because of the necessary corrections to be applied in many instances, even when standard at some one part of the divided head—a uniform lead or pitch of the screw, however much may be the total error (within a reasonable limit), making a great improvement in their construction.

Besides a complete set of end-measure gauges, varying by sixteenths from one-quarter to four inches, there is now ready for inspection a complete plant, consisting of tools and fixtures for producing the standard United States or Franklin Institute thread gauges, every detail having been carefully considered, and every difficulty overcome in the operation for perfecting, not only these standard gauges as to size, but the pitch of the thread, the correct angle, and the width of flat at the top and bottom of the thread; the accuracy with which these details

are carried out is now open to the inspection of all who may be interested, and rapid duplication by *machined* work is now an assured success.

It is with the confidence that the "bottom" has finally been reached, that warrants the Pratt and Whitney Company in thus inviting a thorough inspection of the means available, and the methods employed, in producing standard gauges, and earnestly desiring an impartial verdict as to its accuracy and practicability, whether or not, the system as adopted and carried out, has any real merit upon which the confidence of those using gauges for interchangeable work may be safely based.

DISCUSSION.

PROFESSOR ROBINSON: This paper is of the highest merit and of the greatest possible interest to members of the society, and it is a matter of great satisfaction to the mechanical engineers of this country that there is some one who is able to take hold of this question and treat it so ably as it has been treated; and inasmuch as the methods and results, as stated by the reader, are laid open for inspection by others, I think it is due, in consideration of the amount of effort and expense which has been given to this matter, that the society, as a matter of duty, should appoint a committee to avail itself of the privileges offered of investigating this, and of making such a statement regarding it as will be found advisable; and undoubtedly this is a thing which the society will be willing and anxious to indorse in every particular as a standard of the country. For one, I should be glad to see a committee appointed to give this method the attention it deserves.

PROFESSOR EGLESTON: I do not know whether the members of the society are familiar with the fact that in 1875 the Institute of Mining Engineers appointed a committee on standard gauges, and that committee came to just exactly the conclusion which is expressed here, that diameters or linear measures ranging in fractions of a millimeter or an inch were the only gauges which were standard or could be standard. It is a peculiar gratification, since a large part of the work fell to my hands, to see that idea so fully sustained. It is a matter of a great deal more importance than perhaps would appear just now. I have heard recently that the English engineers are again agitating the question of standards, and are going back to the old caliper

idea. I think this is really a retrograde movement. Most of you may know the fact, but we discovered in the course of our investigations, that in a package of a dozen standard gauges, so-called, of the fixed patterns, no two of them will be alike.

THE PRESIDENT: I suppose the members would be interested if Mr. Pratt would tell us how they went to work in this undertaking. Mr. Pratt told us the story at Hartford, but many gentlemen are here to-day who were not with us then, and I presume it would be very interesting to all to know how Messrs. Pratt and Whitney were led into this prolonged, expensive, and nice investigation.

MR. PRATT: I will relate the story in the briefest possible way. We were called upon to furnish a set of standard thread gauges, and of course the first thing to do was to get the sizes, and upon examining the different makes of gauges we found no two sets alike, and we were forced to commence, as we thought, at the bottom, and at that time, in sending about a foot-piece that we had obtained, we found that those investigating it did not agree upon its value. Among others Professor Rogers was applied to, to investigate the foot-piece, and he had quite a struggle over it with some of our prominent manufacturers of gauges. They could not agree, and Professor Rogers took it upon himself, at his own expense, to go to Europe, and go to the bottom of the thing. He visited the best authorities in Europe, and spent four months there in investigation. After we had obtained the services of one of the graduates of the Stevens Institute, and in connection with Professor Rogers, we constructed two comparators, one of which Professor Rogers has himself, and one of which we have; they being exactly alike. After Professor Rogers returned he investigated the foot-piece, and found it to be about what he had found it to be before, and then, after the new comparator was finished, he found his statement verified. Previous to this time, fortunately, Professor Rogers had been for several years constructing a ruling machine, and he had it completed about this time. We have gone very carefully into this thing. I do not feel egotistic about it at all. What we want is that every one who is interested in the matter, every society that takes any interest in it, should come and examine our methods and our measurements. If they are good, let us have a standard. If they are not, let us throw them away. It has cost us probably twenty thousand dollars

to-day, and I am willing to throw it away if anybody can show us better. We want a standard, and I will not stand in the way of any one else who has a better machine. I feel very much interested in the subject, myself; and I think we shall succeed in what we have undertaken.

LXIV.

THERMODYNAMICS OF CERTAIN FORMS OF THE WORTHINGTON AND OTHER COMPOUND PUMPING ENGINES.

BY

S. W. ROBINSON, PROF. MECH. ENG., OHIO STATE UNIVERSITY.

THE present object is mainly an investigation from a theoretical stand-point of such compound steam-engines as effect the principal part of the expansion of the steam in the act of exhausting from the high-pressure cylinder into a receiver, from which receiver the low-pressure cylinder is supplied with steam. The paper is, however, not confined to this, the Woolf compound with receiver; but the Woolf without a receiver in tandem form, is briefly considered for purposes of comparison.

The high-pressure cylinder is supposed to take its steam at constant pressure from a boiler during its full stroke, then to exhaust into the receiver. The back pressure is the pressure of the steam in the receiver, which will be somewhat variable according to relation of sizes of receiver and cylinders. The low-pressure cylinder steam supply will also vary somewhat in pressure according to pressure in the receiver This cylinder exhausts into the air, or into a condenser; the back pressure due to which is assumed constant in the calculations.

An engine of the kind now considered is shown in Fig. 16, in which the disparity in sizes of cylinders is plainly shown. The "tank" or receiver is situated below the cylinders, and it is some eight or ten times as large as the steam cylinder.

A good idea of the sectional view of this engine can be obtained from Fig. 14, which would be made identical by removing the large cylinder *B* from one side, and the small cylinder *A* from the other side, then placing the remaining two cylinders

opposite each other, and directly over the receiver, or "tank." The valve-gearing, condenser, etc., are alike in both.

PRESSURE VARIATION IN RECEIVER.

The amount and variation of the pressure in the receiver is a complex quantity, depending as it does upon: 1st, the size of the receiver; 2d, upon the sizes of the two cylinders; 3d, upon the mode of working the valves; and, 4th, upon the relative motion of the two pistons. A still greater complexity arises when more than two pistons are employed in one machine, unless two work as one. In the present paper, investigations are limited to a comparatively few cases: as to pistons, only two; and one receiver.

THE PISTON MOVEMENTS.

As to the piston movements three are possible, viz., 1st, they may have entire independence; 2d, they may be limited to an equal number of strokes per minute, with initial points in certain relation; and, 3d, they may be further limited by periods of tarrying. The latter is the case with the Worthington pump.

THE VALVE MOVEMENTS.

As to the valve movements, four are possible, each differing from another in efficiency. Two are selected as special objects for investigation here, viz., the one with the lowest efficiency, and that with the highest. But all these efficiencies approach, and, finally, have a common value as the receiver is enlarged to infinity. For this latter and special case the formulas are much simplified. But as results of much interest and value are obtained from the general formulas, the latter will be deduced and applied. One important service of the general formulas is to point out the fact, that with a certain mode of working the valves, a comparatively small receiver gives a higher efficiency of steam than a larger, or infinite one.

The engine, with two pistons and one receiver, is briefly shown by diagram in Fig. 6, where b, d, are admission valves for high steam, into small cylinder; e, f, exhaust valves from the small cylinder into the receiver; g, h, admission valves from the receiver to the low-pressure cylinder; and j, k, exhaust valves from the low cylinder.

The action of the engine, except where mentioned as otherwise, is considered as alternating between the two pistons; that is to say, one piston stands still at the end of the cylinder, while the other makes its stroke, and conversely. This is the third above mentioned.

The diagram will enable us to indicate the fact of different ways for working the valves. For instance: 1st, suppose b and f open, e and d closed, piston H moving, and piston L standing at end of cylinder. Then with j and k closed, g and h may be either opened or closed. If closed, the steam from f accumu-

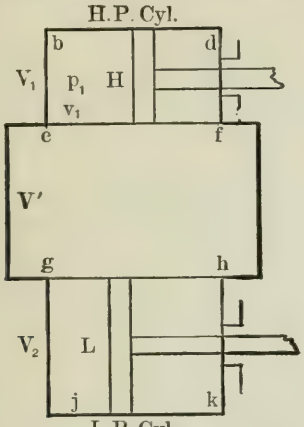


FIG. 6.

lates only in the receiver, while if open, it flows into both the receiver and L cylinder. This option in the valves g and h occasions two valve movements. Again: 2d, suppose piston L moving, while piston H stands at the end of the stroke, then with b and d closed, e and f may be either opened or closed, a second option which occasions two separate valve movements, for this side of the engine. In the combined action of both sides, it appears from the fact that these options are independent of each other, there result four possible valve movements.

THE VALVE MOVEMENTS INVESTIGATED.

Two cases will now be investigated and compared. They are shown in Fig. 7. Both suppose two pistons and one receiver, each with alternate rest and motion of pistons as in the third mode of piston action mentioned above. The first case

is for the least, and the second for the most efficient valve movement.

THE TWO VALVE MOVEMENTS.

In the 1st, and also 2d, of Fig. 7, the engine is represented in the four relations necessarily undergone for completing a cycle of operations. For instance in 1st, we have piston *H* moving while piston *L* stands, then *H* stands while *L* moves, next *H* moves opposite to the first as *L* stands, and finally *H* stands as *L* moves, contrariwise to that of its first stroke. The next move is the same as the first, and thus they continue in repetition. Piston-rods are shown by arrows, which indicate direction of motion. Broken arrows mean standing still.

As to these piston motions: the 2d part of Fig. 7 is like the first, the difference being confined to the valve movements and steam action.

In Fig. 7 all open valves are indicated by arrows. Feathered arrows are put for valves necessarily open, while naked arrows are at valves in option. In the light of these remarks, the valve movements of 1st and 2d may be traced throughout, also steam action. For convenience let the four relations of Fig. 7 be designated as *A*, *B*, *C*, and *D*.

Then in 1st: for the *A* relation we have *H* moving with high steam on one side and exhaust on the other. These are necessary conditions while *H* moves, and hence the arrows are feathered. The exhaust, however, is shown as into the receiver not only, but the *L* cylinder as well, because the valve to the *L*-cylinder is open. But that valve might be closed when the steam would be confined to the receiver with a more rapid rise of pressure. The latter condition is shown in the *A* relation of 2d, hence this arrow is left naked.

Again in the *B* relation, the *H* piston is standing while *L* is making its stroke. The valve between *H* and the receiver is closed in 1st, or it may be open as in 2d, and hence the arrow is featherless as shown.

These references suffice to explain the *C* and *D* relations also, so that both parts of Fig. 7 are understood. Thus in Fig. 7 are exhibited two separate valve movements and four relations of piston motion for each. These will be considered separately.

Respecting the size of the receiver, it is evident that it may

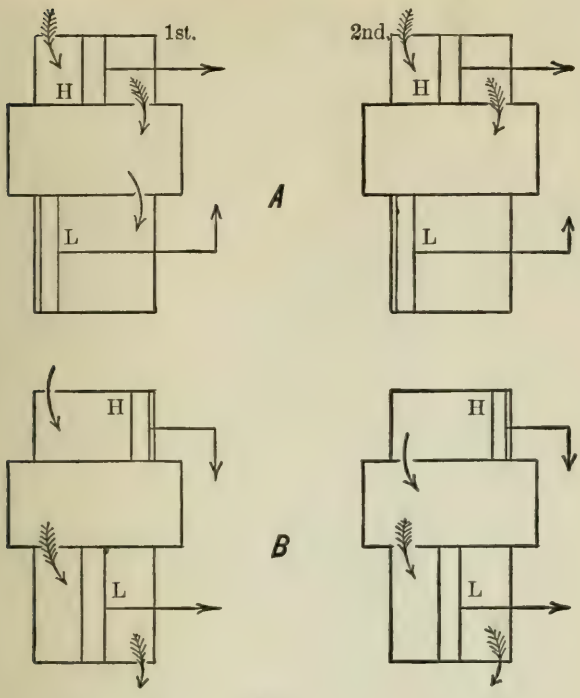
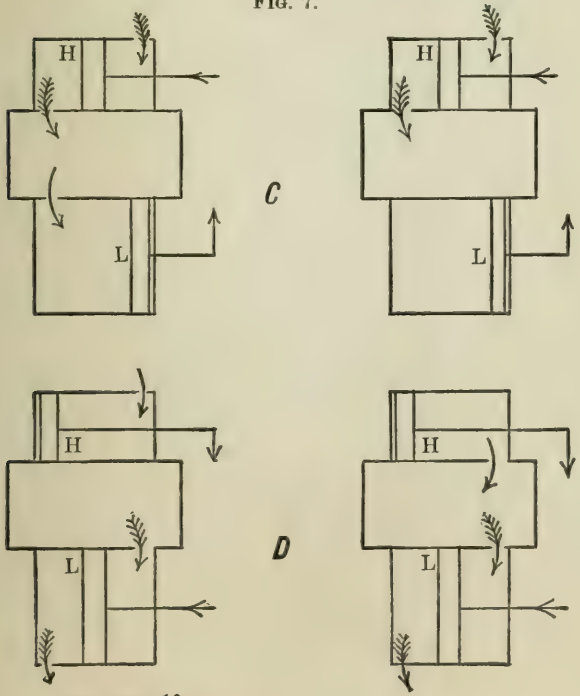


FIG. 7.



be assumed at pleasure, finite or infinite. We will first take it finite.

I. Solution for the First Valve Movement of Fig. 7.

Before making statements of steam action it will be necessary to know specifically the condition of the steam at every point as it passes through the engine. For the 1st part of Fig. 7, the complete diagram of steam action, for continuity of engine movement, is given in Fig. 8.

Let V_1 = volume of the high-pressure cylinder, V_2 = volume of the low-pressure cylinder, and V' = volume of the receiver. These volumes are shown on the diagram in their proper relations. Also the absolute pressures P_1 of the boiler, P_2 of terminal expansion, and P_3 of the exhaust, are shown. Other pressures will be indicated according to lettering of diagram, as, for instance, $P_1 = P_g$ being the pressures at the points I and G. In short, the pressures and volumes are represented by vertical and horizontal distances respectively, with A for the zero or origin.

The Complete Diagram and Indicator Cards.

Now, referring to 1st of Fig. 7, we see that in the A relation the low-pressure or L-piston is standing at the end of its stroke, and with the valve between that cylinder and the receiver open; the steam that made the last L-stroke being retained. Hence the L-cylinder and receiver both together are serving as receiver, while the high-pressure or H-piston is making its stroke and forcing the steam from the H-cylinder into the receiver. The H-piston is moved by steam from the boiler, the same being admitted at full pressure P_1, and full stroke.

Now in Fig. 8, FL represents this high-pressure line of P_1, while KG represents the compression line of the H-piston stroke. It is to be observed that at the initial return of H, the volume is $AC = V_1 + V_2 + V'$; and at the end, it is $AD = V_2 + V'$.

Next, in the B-relation of 1st of Fig. 7, the valves of L are reversed, as H completes its stroke, the steam in the L-cylinder being exhausted In Fig. 8 this exhaust is shown by a cutting off of the steam GI, and leaving only that in the receiver, of volume $V' = AE$, to act upon the L-piston.

The *H*-piston now stands while the *L*-piston makes its stroke with a change of active steam volume from V' to $V' + V_2$; and producing the expansion line *IH*, Fig. 8. Next the valves of *L*, Fig. 7, remain, while the valves of *H* reverse; so that the *L*-piston stands while the *H*-piston moves as in the *C* movement.

Now as the valves of *H* reverse, the high steam exhausts into the receiver and *L*-cylinder together, giving the expansion line *FJ* for the high steam, and the compression line *HJ* for

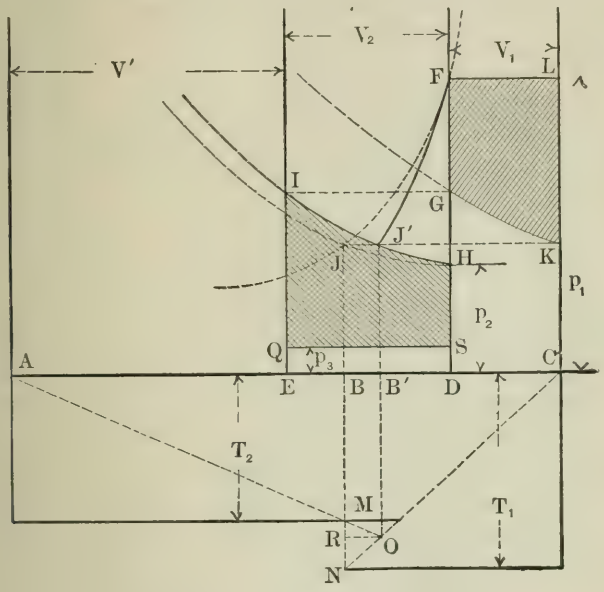


FIG. 8.

the low steam, till both arrive at a common pressure at *J*. The expansion line *FJ* is to be drawn with *C* as the point of zero volumes and pressures; while *HJ* has *A* for the like point. Here the steam, isodynamically brought down from P_1 at *F*, will be hotter than that brought up from P_2 at *H*; and as they commingle, the volume *JK* decreases by giving up heat, and the volume *AB* increases by receiving that heat. But as the same weight of steam must necessarily be exhausted from the high cylinder as from the low at a stroke, it follows that the steam *JK* introduced must have equal weight with the steam *GI* exhausted. Hence the volume *JK* must

shrink by cooling to some volume $J'K$, such that J' lies on the expansion curve IH; because when AC is compressed along KG to AD, then $J'K$ must compress to GI, and AB to AE. The curves KG and $J'I$ are of like sort, with the point A for the zero of pressures and volumes.

Now H commences its stroke with a back pressure $P_3 = CK$, and the volume $AC = V_1 + V_2 = V$. At the end of the stroke this volume has been reduced to AD, giving the compression line KG. At the end of this stroke the valves of L are reversed, causing the immediate exhaust from L of the volume $GI = V_2$, when in the L-stroke the expansion curve IH, etc., is formed as before.

Thus it appears that $FGKL$ is the indicator card of the H-cylinder, while $HIQS$ is the card for the L-cylinder. The work done by these cylinders will be proportional to these areas.* The back pressure is $EQ = P_3$.

Nature of the Expansion and Compression Lines.

Having traced out the action of the engine and of the steam as it is worked in it, we are prepared to inquire into the specific nature of the various lines of the complete diagram, Fig. 8, from the standpoint of thermodynamics. Thus the compression curve KG is adiabatic, and such that if the steam is saturated at K, it is superheated at G by the compression. Hence, as the steam will be shown to be not far from saturated at K, this curve is an adiabatic for superheated steam. The same is true of $J'I$, because as K is compressed to G, J' is compressed to I. After the exhaustion of the volume GI, the curve IJ' is retraced by expansion with the same steam as was just compressed along $J'I$. But with $J'H$ the case is to some extent different, before explaining which, we must consider JH and JF. With respect to the latter, it is to be observed that at the end of the stroke of the L-piston, the volume $V' + V_2$ is ready to receive the high-steam exhaust from the H-cylinder. Here the low-steam pressure is $DH = P_2$, and high-steam pressure $DF = P_1$; while the volumes are $V' + V_2 = AD$, and $V_1 = DC$, respectively. Now as the valve from H to the receiver opens, these two portions of steam

* Cards actually taken with the indicator, however, have equal lengths. When modified to lengths FL and QS the proportion is true.

coalesce * into a common body, whose volume is simply the sum of the previous partial volumes; that is to say,

$$(V_2 + V') + V_1 = V_1 + V_2 + V';$$

and the resulting pressure is *BJ*. In this act no exterior work is performed by the mass of steam in the volume *AC*, because, for the instant during which this commingling occurs, the pistons of the engine do not move perceptibly. This act is therefore governed by *Hirn's law;* that is to say, because no external work is done during the change, the internal energy of the mass of steam remains constant. The curve representing this action is the so-called *isodynamic curve*. Hence the pressure *BJ* is to be found at the intersection of two isodynamic lines *FJ* and *HJ*; the first representing the isodynamic expansion of the volume V_1, and the second, the compression of the volume $V' + V_2$.

Though these curves serve to determine the point *J*, or resulting pressure *BJ*, yet it is to be understood that they do not represent the operations which actually take place in the two portions of steam, because the low steam is in reality compressed adiabatically from *H* to *J'*, and the work *B'DHJ'* performed. This work is performed by the expansive action of the high steam while actually expanding along some line *FJ'*, and not *FJ*. This curve, however, will lie above the adiabatic through *F*, because in expanding along *FJ'* the steam is not doing its full work, the work actually done being only *B'DHJ'*, instead of an area extending fully up to the expansion line. Hence, *J'* instead of *J*, represents the actual resulting point of pressure.

Now the points *J* and *J'* are expected to be *very nearly* in a horizontal line, but may not be exactly so for several practical reasons. The expansion *J'H* will probably be mostly adiabatic below the saturation-point, the point of change from superheat to supersaturation lying somewhere on *J'H*, but not far from *J'*. Much of the supersaturation moisture due to this expansion may be precipitated while the *L*-piston tarries

* This, however, is only partially true, since some of the steam remains in the *H*-cylinder till forced out through the open valve into the receiver during the return stroke. Though the pressure is common, yet the temperature and density of that remaining in the cylinder will probably differ somewhat from that in the receiver.

at the end of its stroke, so that the compression heat of HJ' acts at a disadvantage in re-evaporating that moisture. The moisture thus precipitated may accumulate in the receiver as water, and require to be drawn off by a cock. To show that at the end of the stroke IH the steam is necessarily below the saturation-point, we observe that KG and $J'I$ are counteractions which offset each other, as already explained, and hence have no influence on the final condition of saturation. Now, referring to the isodynamic lines, the expansion FJ gives rise to superheat while the compression HJ occasions condensation. These actions nearly compensate each other, because, though the intensity for FJ is greater than for HJ, yet the quantity of steam concerned in JH is greater: assuming that these exactly neutralize, then the saturation-point lies very near to J', and below it if supersaturation moisture is precipitated in the receiver.

It appears, therefore, that the expansion line IH is of two kinds, viz., from I to some point near J' it is adiabatic for superheated steam, while from the latter point to H it is adiabatic for supersaturated steam.

Equation for Expansion and Compression Lines.

In looking over the several forms of curve shown on Fig. 8, it appears that there are three, all of which are provided for in the convenient approximate equation

$$\left.\begin{aligned} &Pv^x = \text{constant} = P_1 v_1^x \\ \text{or,}\quad &\frac{P}{P_1} = \left(\frac{v_1}{v}\right)^x \end{aligned}\right\} \qquad (1)$$

As this equation is approved for ordinary purposes by high authority, it will be adopted in the present investigation.

Table of Values of x, and Authority.

Values of x =	Adiabatic Expan. Initial Saturation, ∞. m	Curve of Saturation. s	Adiabatic for Superheated Steam. a	Isodynamic for Superheated Steam. n
Rankine, . . .	$\frac{10}{9} = 1.11111$	$\frac{17}{16}$, and 1.0646	1.3	Not given.
Cotterill, . . .	$1.035 + \frac{\infty}{10}$	" "	"	Bet. s and 1
Zeuner, ...	" "	1.0646	$\frac{4}{3} = 1.3333$	1.0456
Röntgen, . . .	" "	"	"	"

This table and (1) will give us the equation of any curve desired. Accordingly we find

$$\left.\begin{array}{ll} \text{Curve } FJ & \text{isodynamic and } x = n \\ \text{“ } HJ & \text{“ “ “ “} \\ \text{“ } GK & \text{adiabatic for superheat and } x = a \\ \text{“ } IJ' & \text{“ “ “ “ “} \\ \text{“ } J'H & \text{“ initial sat. } x = m. \end{array}\right\} \quad (2)$$

In these we not only have authority for a variety of values of x, but in m the "steam quantity" ∞ suggests that the value of x may be determined even by estimation from such facts as may effect ∞. Accordingly, for an expansion where only partial work of expansion is performed, x may be found to lie between $\frac{4}{3}$ and 1.0456 for superheated steam. When $\infty = 1$ we have $x = 1.135$. It is to be observed, however, that the form of curve, according to equation (1), is dependent on the value of the exponent, so that the general equations may be considered as suitable for any forms of these lines.

Insignificance of JJ'.

For the difficulty and complexity resulting from the attempt to account for the change JJ' in the general equations, we will first examine that quantity to see if worthy of that trouble.

Regarding H as a point of intersection of the adiabatic and isodynamic curves $J'H$, and JH, we may find JJ' by aid of (1), on the supposition that it is wholly due to the deviation of these curves, thus:

$$\frac{P_j}{P_2} = \left(\frac{V_2 + V'}{V_j}\right)^n \text{ and } \frac{P_j}{P_2} = \left(\frac{V_2 + V'}{V_j'}\right)^m$$

Solving for V_j and V_j', and taking their ratio, we have

$$\frac{V_j'}{V_j} = \left(\frac{P_j}{P_2}\right)^{\frac{1}{n} - \frac{1}{m}} = \left(\frac{P_j}{P_2}\right)^{\frac{m-n}{mn}} = \left(\frac{P_j}{P_2}\right).0753,$$

where m is taken at 1.135.

The volumes V_j and V_j' are reckoned from the origin A, Fig. 8.

As an example, take $V' = V_2 = 2V_1$, the receiver being unusually small, then the value of $\frac{P_j}{P_2}$ = about $\frac{1}{3}$. Introducing this and solving, we find,

$$\frac{V_j'}{V_j} = 1.022 = \frac{V_j + JJ'}{V_j} = 1 + \frac{JJ'}{\quad}$$

whence

$$JJ' = .022\, V_j$$

from which it appears that the greatest practical value of JJ' is about two per cent. of the volume V_j, or of AB.

Again, take what may be a moderate value of $V' = 4\, V_2 = 8\, V_1$ then a sketched diagram will show that $\frac{P_j}{P_2}$ = about $\frac{9}{8} = 1.125$, whence

$$\frac{V_j'}{V_j'} = 1.009$$

or

$$JJ' = .009\, V_j,$$

which is less than one per cent. Hence it appears that that part of JJ' which is due to the deviation of these curves, may probably be neglected in practice without serious results.

Should it be desirable to account for JJ', it will perhaps be most convenient to do so on the drawing-board, by laying off the volumes and pressures, and drawing the curves by trial so as to fit. In such case the preliminary diagram may be drawn by aid of an approximate solution afterwards given, for which $x = 1$ in Eq. (1).

To Account for JJ' on the Supposition of Heat.

In this case the drawing-board may be preferred. Use temperatures and a diagram, as shown in the lower part of Fig. 8. As the temperatures for the isodynamic lines through J are each nearly constant, let the absolute temperatures τ_1 and τ_2 of the steam at admission and at the end of $J'H$ be laid off downward, as shown. Draw lines to M and N, meeting JMN. Then draw straight lines AMO and CNO, giving the intersection O. Then the line through O parallel to NJ should give the point J'. The diagram ANC depends upon the law of Gay Lussac, relating to volume and temperature, for constant pressures in gases, viz., by symbols

$$\frac{v}{\tau} = \frac{v^1}{\tau^1}.$$

In superheated steam this very nearly holds true. In the diagram the application is $AB : BM :: RO : RM$, and $CB : BN :: RO : RN$. The two portions of steam are first supposed reduced to the common pressure P_j, by the isodynamic,

or nearly constant temperature expansion FJ, and the like compression HJ. The volume BC then has the temperature τ_1 of P_1, and the volume AB the temperature τ_2 of p_2. The change JJ' is that by which the portion BC shrinks, and of AB expands, while the temperatures τ_1 and τ_2 merge into one temperature, $\tau_j = BR$.

Repeated trials should be made until JJ' is a horizonal line from the intersections J of the isodynamics to the adiabatic IH, and with $J'K$ and GI also horizontal.

But as the correction to the volume $AB = V_j$ is usually less than one per cent., it is probable that the discrepancies in results of efficiency or duty of engine due to it will be too small to merit serious consideration.

Hence, in the following general equations, the points J and J' will be regarded as coincident; and the entire expansion line IH will be treated as of one form, or as characterized by one value of the exponent x in Eq. (1).

Area of the Indicator Cards; and General Equations.

An expression for the area of, or work represented by an indicator card like $FGKL$, Fig. 8, for one pound of steam in the usual notation is

$$p_1 v_1 - \int p dv \qquad \text{(a)}$$

where $p_1 = FD$, is the specific pressure of the steam, or absolute pressure per unit surface; usually pounds per square foot: $v_1 = FL$ the specific volume, or volume per unit weight; usually cubic feet per pound; and where p is the varying pressure under the curve GK. The first term of (a) gives the whole area $FDCL$, while the second term gives the area $GDCK$, the difference expressed being the area proposed. A similar expression answers for $IQSH$, except for the interchanging of terms, viz.:

$$\int p dv - p_3 v_2. \qquad \text{(b)}$$

These are for one pound, and not for the actual volumes V_1 and V_2. Hence the areas in (a) and (b) are simply *like* those of Fig. 8, but not equal to them.

But in the present case it will probably be most convenient

to apply our reasoning to the actual volumes V_1, V_2, and V' of the high cylinder, low cylinder, and receiver respectively.

For the present convenience let A = the area of the high-pressure piston, and l the length of its stroke. Then

$$V_1 = Al, \tag{3}$$

or multiplying through by P.

$$P_1 V_1 = P_1 Al = \text{actual area } FDCL. \tag{4}$$

Similarly below the expansion line GK.

$$\int_0^l P A \, dx = \text{actual area } GDCK, \tag{5}$$

or

$$= \int_{L_1}^{L_2} P A \, dx, \tag{5}$$

if L_1 = length AD and L_2 = length AC. The pressure P is here variable, but according to (1) and (2) the zero of volumes for GK being at A, Fig. 8.

$$\frac{P}{P_g} = \left(\frac{L_1}{x}\right)^a = \left(\frac{V' + V_2}{V}\right)^a \tag{5½}$$

Hence (5) becomes

$$\text{Area } GDCK = AP_g L_1^a \int_{L_1}^{L_2} \frac{dx}{x^a}$$

$$= AP_g L_1^a \frac{1}{1-a}\left(L_2^{1-a} - L_1^{1-a}\right);$$

or, since $L_2 = L_1 + l$.

$$GDCK = AP_g L_1^a \frac{1}{1-a}\left\{(L_1 + l)^{1-a} - L_1^{1-a}\right\}$$

$$= AP_g L_1 \frac{1}{a-1}\left\{1 - \left(\frac{L_1}{L_1 + l}\right)^{a-1}\right\}$$

$$= P_g \frac{V_2 + V'}{a-1}\left\{1 - \frac{1}{\left(1 + \frac{V_1}{V_2 + V'}\right)^{a-1}}\right\} \tag{6}$$

the last transformation depending on the relations $Al = V_1$ and $\frac{l}{L} = \frac{V_1}{V_2 + V'}$.

This equation might be used in its present form for all cases except when $x = 1$, in Eq. (1), an assumption which it is desirable to make eventually. But for $x = 1$ (6) becomes indeterminate in the form now given. This difficulty is avoided, however, and in some respects with greater convenience, by developing $(L_1 + l)^{1-a}$ into a series by the binomal theorem, whence we obtain

$$GDCK = AP_g l \left\{ 1 - \frac{a}{2}\frac{l}{L_1} + \frac{a(a+1)}{2.3}\frac{l^2}{L_1^2} - \&c. \right\} \quad (c)$$

$$= P_g V_1 \left\{ 1 - \frac{a}{2}\frac{V_1}{V_2 + V'} + \frac{a(a+1)}{2.3}\left(\frac{V_1}{V_2 + V'}\right)^2 - \&c. \right\}$$

$$= P_g V_1 M \quad (7)$$

where for brevity we put M in place of the series, or where

$$M = 1 - \frac{a}{2}\frac{V_1}{V_2 + V'} + \frac{a(a+1)}{2.3}\left(\frac{V_1}{V_2 + V'}\right)^2 - \frac{a(a+1)(a+2)}{2.3.4}\left(\frac{V_1}{V_2 + V'}\right)^3 + \&c. \quad (I)$$

In the denominators, $2.3 = 6$, and $2.3.4 = 24$, &c.

For the particular case $a = 1$, the integral becomes, for the small cylinder

$$\left.\begin{aligned} (GDCK)_{a=1} &= AP_g L_1 \, hyp.\,log.\left(1 + \frac{l}{L_1}\right) \\ &= P_g (V_2 + V') hyp.log.\left(1 + \frac{V_1}{V_2 + V'}\right) \end{aligned}\right\} (8)$$

In these equations P_g is the absolute pressure DG, $= EI$.

Similarly for the area $IEDH$, taking the point A, Fig. 8, as the zero of volumes, and putting

$$A'l' = V_2 \text{ and } \frac{l'}{L'_1} = \frac{ED}{AE} = \frac{V_2}{V'},$$

and substituting them for Al and $\frac{l}{L_1}$ in the equation preceding (6), gives for the large cylinder the area

$$IEDH = P_g \frac{V'}{a-1}\left\{ 1 - \frac{1}{\left(1 + \frac{V_2}{V'}\right)^{a-1}} \right\} \quad (8\tfrac{1}{2})$$

or, by the series in equation (c)

$$IEDH = P_g V_2 \left\{ 1 - \frac{a}{2}\frac{V_2}{V'} + \frac{a(a+1)}{6}\left(\frac{V_2}{V'}\right)^2 - \frac{a(a+1)(a+2)}{24}\left(\frac{V_2}{V'}\right)^3 + \text{\&c.,} \right\}$$
$$= P_g V_2 N, \tag{9}$$

where for brevity we put N in place of the series, or where

$$N = 1 - \frac{a}{2}\frac{V_2}{V'} + \frac{a(a+1)}{2.3}\left(\frac{V_2}{V'}\right) - \frac{a(a+1)(a+2)}{2.3.4}\left(\frac{V_2}{V'}\right)^3 + \text{\&c.} \tag{II}$$

For $a = 1$, we have

$$(IEDH)_{a=1} = P_g V' hyp.\ log.\left(1 + \frac{V_2}{V'}\right). \tag{10}$$

Now the work done in the high-pressure cylinder, per stroke, is

$$P_1 V_1 - GDCK. \tag{11}$$

Also in the low-pressure cylinder it is

$$IEDH - P_3 V_2. \tag{12}$$

Hence, when the engine is working in continuity under the first valve movement of Fig. 7, and giving the diagram of Fig. 8, then, for one stroke of each piston in regular order of continuity, the same being the half of a complete cycle of operations detailed in Fig. 7, or, for each high-pressure cylinder full of steam, the work done will be the sum of (11) and (12); or, the effective work per stroke of both cylinders is $U = (P_1 V_1 - GDCK) + (IEDH - P_3 V_2)$

$$= P_1 V_1 - P_g V_1 M - P_3 V_2 + P_g V_2 N$$
$$= P_1 V_1 \left\{ 1 + \frac{P_g}{P_1}\left(\frac{V_2}{V_1} N - M\right) - \frac{P_3 V_2}{P_1 V_1} \right\} \tag{13}$$

and for $a = 1$

$$U' = P_1 V_1 \left\{ \begin{array}{l} 1 - \dfrac{P_g}{P_1}\dfrac{V_2 + V'}{V_1} hyp.\ log.\left(1 + \dfrac{V_1}{V_2 + V'}\right) \\ \\ - \dfrac{P_3 V_2}{P_1 V_1} + \dfrac{P_g V'}{P_1 V_1} hyp.\ log.\left(1 + \dfrac{V_2}{V'}\right) \end{array} \right\} \tag{14}$$

The work performed by the engine for a complete cycle of operations, including two strokes of each cylinder, as already

explained, will evidently be equal to twice the work given by (13) or (14).

In attempting to apply either (13) or (14), everything is seen to be in known terms except P_g. This is the absolute back pressure in the high-pressure cylinder at the termination of its stroke, it is the absolute forward pressure in the low-pressure cylinder at the beginning of its stroke, and also it is the pressure at the same time in the receiver. Fig. 8 shows that this depends on many things, and that it is in no case, in itself, arbitrary, but that, in an actual engine, it is self-adjusting according to pressure of admission, dimensions of cylinders and receiver, mode of valve action, and laws of expansion.

To express P_g in convenient terms, we may write from Fig. 8 and by aid of (1) and (2), regarding J and J' as coincident,

$$\frac{P_1}{P_j} = \left(\frac{JK}{FL}\right)^n = \left(\frac{JK}{V_1}\right)^n.$$

Also,

$$\frac{P_1}{P_j} = \frac{P_g}{P_k} = \frac{P_g}{P_j} = \left(\frac{AC}{AD}\right)^a = \left(\frac{V_1 + V_2 + V'}{V_2 + V'}\right)^a = \left(1 + \frac{V_1}{V_2 + V'}\right)^a$$

Again, from the fact that the intercepts on horizontal lines lying between two curves constructed from (1) with one value for x and different values of $P_1 V_1$, are proportional to the abscissas to the intersection points of the horizontal lines with either curve, we may write

$$\frac{JK}{GI} = \frac{JK}{V_2} = \frac{AC}{AD} = \frac{V_1 + V_2 + V'}{V_2 + V'} = 1 + \frac{V_1}{V_2 + V'}.$$

Eliminating JK and combining, we get

$$\frac{P_g}{P_j} \cdot \frac{P_j}{P_1} = \frac{P_g}{P_1} = \left(1 + \frac{V_1}{V_2 + V'}\right)^a \cdot \left(\frac{V_1}{V_2}\right)^n \cdot \left(1 + \frac{V_1}{V_2 + V'}\right)^{-n}$$

$$= \left(\frac{V_1}{V_2}\right)^n \cdot \left(1 + \frac{V_1}{V_2 + V'}\right)^{a-n} \qquad (15)$$

Eliminating $\frac{P_g}{P_1}$ from (13) and (14) by aid of (15), we find for the work of the half cycle, or for one stroke each of the two cylinders in continuity,

$$U = P_1 V_1 \left\{1 + \left(\frac{V_1}{V_2}\right)^n \cdot \left(1 + \frac{V_1}{V_2 + V'}\right)^{a-n} \left(\frac{V_2}{V_1} N - M\right) - \frac{P_3 V_2}{P_1 V_1}\right\} \qquad (16)$$

and for the hyperbolic expansion where a and $n = 1$, we have

$$U' = P_1 v_1 \left\{ \begin{array}{l} 1 - \dfrac{V_2 + V'}{V_2} \, hyp.\, log. \left(1 + \dfrac{V_1}{V_2 + V'}\right) \\ - \dfrac{P_3 V_2}{P_1 V_1} + \dfrac{V'}{V_2} \, hyp.\, log. \left(1 + \dfrac{V_2}{V'}\right) \end{array} \right\}, \qquad (17)$$

all quantities being in known terms. If $a = n$, the term $\left(1 + \dfrac{V_1}{V_2 + V'}\right)^n$ drops from (16).

If $V' = \infty$, and a and n as in (16), we get

$$U'' = P_1 V_1 \left\{ 1 - \left(\frac{V_1}{V_2}\right). + \left(\frac{V_1}{V_2}\right)^{n-1} - \frac{P_3 V_2}{P_1 V_1} \right\} \qquad (18)$$

If $V^1 = \infty$, and a and $n = 1$, we get

$$U''' = P_1 V_1 \left(2 - \frac{V_1}{V_2} - \frac{P_3 V_2}{P_1 V_1}\right) \qquad (19)$$

Two additional expressions for the work may also be written out readily, viz.:

For (16) with $n = 1$

$$U^{iv} = \qquad (20)$$

and for (16) with $a = 1$

$$U^{v} = \qquad (21)$$

In these expressions,

P_1 = absolute pressure of admission, lbs. per square foot = 144 (p_1' + 14.7), for p_1' = lbs. per square inch of boiler pressure.

P_3 = absolute back pressure to low-pressure cylinder lbs. per square foot of the atmosphere for exhausting into air, or of the condenser for condensing engines.

V_1 = volume of high-pressure cylinder in cubic feet.

V_2 = volume of low-pressure cylinder in cubic feet.

V' = volume of receiver and connecting pipes in cubic feet.

M and N being given by equations (I) and (II).

These equations are useful in calculating the amount of work that can be done by an engine, or in calculations for duty.

In practice any one of these equations can be used according to accuracy required, (16) being necessary for the greatest degree of exactness. It is seen, however, by (2) and the accom-

panying table that a much wider departure from truth results when $a = 1$ than when $n = 1$. When the steam is very wet the actual value of a will be much nearer unity than for dry steam. In such case some value of n should be used in place of a. Fig. 8, also, will indicate in some degree to what extent, in any practical case, we jeopardize the result by taking V' infinite in the calculations.

Pressure at Different Points of Steam Action.

It is often desirable to know the pressure at different points of the steam action in the engine. To this end we have (15) for the terminal pressure, p_g, in the high cylinder, and initial pressure in the low cylinder. This shows that if $a = n$ it matters not with p_g whether $V' = \infty$ or not. From this it appears that for $a = n$ the smaller we make V' the greater is the proportion of work done by the small and less by the large cylinder.

For the initial and final pressures in the low-pressure cylinder we have the relation

$$\frac{P_g}{P_2} = \left(\frac{V_2 + V'}{V'}\right)^a = \left(1 + \frac{V_2}{V'}\right)^a \tag{22}$$

combining with (15)

$$\frac{P_2}{P_1} = \left(\frac{V'}{V_2 + V'}\right)^a \cdot \left(\frac{V_1}{V_2}\right)^n \cdot \left(1 + \frac{V_1}{V_2 + V'}\right)^{a-n} \tag{23}$$

The 4th equation preceding (15), combined with the 2d, gives

$$\frac{P_1}{P_k} = \frac{P_1}{P_j} = \left(\frac{V_2}{V'}\right)^n \cdot \left(1 + \frac{V_1}{V_2 + V'}\right)^n \tag{24}$$

These equations show that for $V' = \infty$ we have

$$\frac{P_g \text{ or } P_j \text{ or } P_2}{P_1} = \left(\frac{V_1}{V_2}\right)^n \tag{24½}$$

which is the constant pressure of the infinite receiver, and toward which this pressure approximates as V' is made large.

The varying pressure for the stroke of either cylinder may be obtained by aid of equation (5½).

Equation (15) shows that if $a = n$, as it will very nearly for wet steam, the pressure at G or I, $= P_g$, will be entirely inde-

pendent of V' whether infinite or finite. In this case the pressure P_g is what might be termed the pivotal pressure, since it remains fixed while all other pressures, except P_1 and P_3, vary with V'. The effects of this on the diagram are that the lines GK, or III, swing around the points G and I as pivots, becoming flatter as V' is enlarged, or steeper as it is diminished. Hence as V' is enlarged, the work produced in V_1 decreases, while in V_2 it increases. Considering these variations, a look at diagram, Fig. 8, shows that the efficiency of this engine increases with V', and is a maximum when V' is infinite.

When $V' = 0$, V_2 does no work, and the engine does worse than a non compound, but equals it when $IQSH = GSS'K$.

Relative Areas of Indicator Cards.

It is also desirable to know the relation between the work developed in the high-pressure cylinder and the low. From the expressions (13) and (15) above given, we readily find

$$\frac{Wk.H.\text{-}Cyl.}{Wk.L.\text{-}Cyl.} = R = \frac{1 - M\left(\frac{V_1}{V_2}\right)^n \cdot \left(1 + \frac{V_1}{V_2 + V'}\right)^{a-n}}{N\frac{V_2}{V_1}\left(\frac{V_1}{V_2}\right)^n \cdot \left(1 + \frac{V_1}{V_2 + V'}\right)^{a-n} - \frac{P_3 V_2}{P_1 V_1}}. \tag{25}$$

For the hyperbolic expansion this ratio is

$$R' = \frac{1 - \frac{V_2 + V'}{V_2} hyp.\ log.\left(1 + \frac{V_1}{V_2 + V'}\right)}{\frac{V_1}{V_2} hyp.\ log.\left(1 + \left(\frac{V_2}{V'}\right) - \frac{P_3 V_2}{P_1 V_1}\right.}. \tag{26}$$

If $V' = \infty$, and a and n are as in (25)

$$R'' = \frac{1 - \left(\frac{V_1}{V_2}\right)^n}{\left(\frac{V_1}{V_2}\right)^{n-1} - \frac{P_3 V_2}{P_1 V_1}}. \tag{27}$$

If $V_1 = \infty$, and a and $n = 1$

$$R''' = \frac{1 - \frac{V_1}{V_2}}{1 - \frac{P_3 V_2}{P_1 V_1}}. \tag{28}$$

Heat for Producing Steam.

The heat required to produce the steam used at a stroke of the high-pressure cylinder will be the total heat of evaporation from the temperature of feed water, and at the temperature of boiler pressure.

Let V_1 = the volume of steam required per stroke of high cylinder in cubic feet.

D_1 = the weight per cubic foot of the steam as supplied to the engine.

H_1 = the dynamical value of the total heat of evaporation per pound from 32° F., at the temperature of boiler pressure steam; that is, the heat to raise the temperature of the water from 32° F. to the temperature of the steam in the boiler, added to the latent heat of evaporation at the latter temperature. (Convenient values are given for this in the tables of *Rankine's Steam Engine*).

t_f = the actual temperature, Fahr., of the feed water.

J = Joule's equivalent, = 772 ft.-lbs.

Then the total heat consumed per high-pressure cylinder full of steam in dynamical value, or ft.-lb. units, is

$$H = V_1 D_1 (H_1 - J(t_f - 32°)). \tag{29}$$

Efficiency of the Engine.

The efficiency of the engine is obtained by dividing the ft.-lbs. of work developed by the engine for each high-pressure cylinder full of steam, by the dynamical value of the heat required to produce that steam; that is, the

$$\text{Efficiency} = \frac{U}{H}. \tag{30}$$

Maximum Efficiency.

In the compound engine now under consideration, the efficiency will, it appears, vary with changes in the relative sizes of the cylinders. For instance, if both cylinders are of equal size and the receiver is very large, the first cylinder does almost no work, because the receiver must now receive the same volume of steam as it discharges, per stroke; and there will be no expansion between the cylinders. Hence the engine now works without expansion, and with consequent

low efficiency. On the other hand, if there be a very great disparity of cylinder sizes, the low-pressure cylinder may exhaust the steam so rapidly from the receiver as to carry its pressure as low or even lower than the back pressure. At the limit of equal back and receiver pressure, no work will be done by the low-pressure cylinder, and the high-pressure cylinder exhausts, in effect, into the back pressure direct. Here again we have no working expansion, and a correspondingly low efficiency. It is evident that between these limits there exists a relation of sizes which will give a maximum of efficiency.

To determine this relation, assume a fixed volume of V_1 and of V', while V_2 is made to vary. In this way the quantity of steam used per stroke is invariable, so that the denominator of (30) is constant.

Hence, for the maximum of (30), we have only to examine the numerator, or to examine (16), (17), or (18), etc., according to contemplated accuracy. This could be done by working out several values from which to construct a curve, the maximum ordinate of which corresponds to the maximum sought. This plan is probably advisable for (16) and (17).

If we place the differential coefficient of U'' with respect to V_2 from (18) equal zero, we get after reduction, for the case $V' = \infty$,

$$\frac{P_3}{P_1} = \left(\frac{V_1}{V_2}\right)^n \cdot \left(n\left(\frac{V_1}{V_2}\right)n - 1\right), \tag{31}$$

an equation which is irresolvable for the desired quantity, viz., $\frac{V_1}{V_2}$. But for a series of assumed values of $\frac{V_1}{V_2}$ the corresponding values of $\frac{P_3}{P_1}$ may be computed and tabulated. A sufficiently extended table would answer all cases, requiring conditions for the maximum efficiency.

If $n = 1$, then (31) reduces to

$$\frac{P_3}{P_1} = \left(\frac{V_1}{V_2}\right)^2. \tag{32}$$

Eliminating $\frac{P_3}{P_1}$ between (31) and (18) we find the maximum of U'', or for the infinite receiver, with n as in (18);

$$U''_{\max.} = P_1 V_1 \left\{ 1 - \left(\frac{V_1}{V_2}\right)^n \left(1 + n - n\,\frac{V_2}{V_1}\right) \right\}. \qquad (32\tfrac{1}{2})$$

From this, for $n = 1$, or for (32) in 19, we obtain for $V' = \infty$ and $n = 1$ the maximum of U'''.

$$U'''_{\max.} = 2P_1 V_1 \left(1 - \frac{V_1}{V_2}\right)$$

$$= 2P_1 V_1 \left(1 - \frac{P_1}{P_3}\right)^{\frac{1}{2}}. \qquad (33)$$

Conditions for Equal Work of Cylinders.

In practice it is probably desirable that the cylinders do equal work, particularly so in the Worthington pumping engine, where the especially important point is made of destroying the "water hammer" in connection with the water-valve action; and of maintaining perfect uniformity of pressure and motion of the travelling water column.

To obtain an equation which shall express the conditions necessary for such equality of work of the two cylinders, we have only to place the numerator and denominator of (25) equal to each other, which becomes

$$\frac{P_3 V_2}{P_1 V_1} = \left(M + N\frac{V_2}{V_1}\right)\left(\frac{V_1}{V_2}\right)^n \left(1 + \frac{V_1}{V_2 + V'}\right)^{a-n} - 1. \qquad (34)$$

In using this equation it will be necessary to assume a set of volumes and find the ratio $\frac{P_3}{P_1}$, a satisfactory value for which may require several trials.

If $V' = \infty$ (34) reduces to

$$\frac{P_3 V_2}{P_1 V_1} = \left(1 + \frac{V_2}{V_1}\right)\left(\frac{V_1}{V_2}\right)^n - 1. \qquad (35)$$

If $n = 1$, also,

$$\frac{P_3}{P_1} = \left(\frac{V_1}{V_2}\right)^2. \qquad (36)$$

This last is the same as (32), which gives the condition for a maximum efficiency. Hence, for the case that the receiver has an infinite volume, and $n = 1$, the engine works with its maximum efficiency when the cylinders do equal portions of the work. When the receiver is eight or ten times as large as the

low-pressure cylinder, this engine, with its valves working as stated, is not far from working with its maximum efficiency.

II. Solution for the Second Valve Movement of Fig. 7.

The complete diagram of steam action in continuity for this case is shown in Fig. 9. The notation is as before, AC being the volume of the three parts V_1, V_2, and V'.

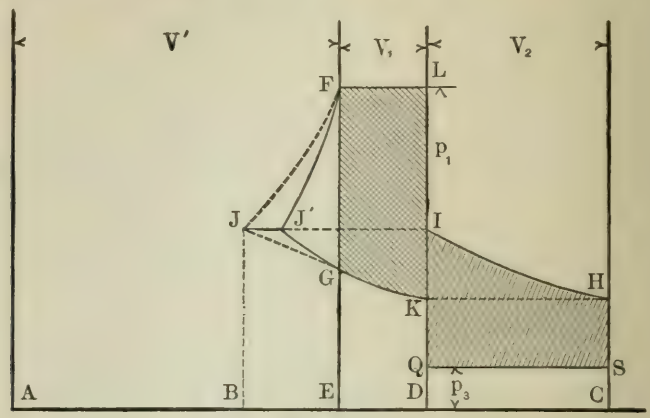


Fig. 9.

The piston motions are the same here as shown in Fig. 7, and, indeed, the same as in Case I. The sole cause for the difference in diagrams is in the valve movement, as indicated in the second part of Fig. 7.

The Complete Diagram and Indicator Cards.

When the H-piston has completed its forward stroke, all under the full boiler pressure P_1, the boiler steam is to be immediately cut off, and to be exhausted into the receiver. The resulting pressure is $BJ = DI = P_3$. The valve remains open, and H-piston stands, while the L-piston makes its stroke. The latter starts while the volume of active steam is that in the receiver and H-cylinder together, and equals $AD = V_1 + V'$. Hence, the expansion line for this stroke is IH, drawn with the point A for the zero of volumes. Immediately on completing the stroke, the admission valve from the receiver is closed, retaining the steam in the L-cylinder while its piston stands. Consequently the H-piston starts its stroke with a back pressure $DK = CH$ of the terminal stroke of the

L-piston. The volume subject to this back pressure is *AD* at the start of the *H*-piston, but during this stroke it is compressed to *AE*, giving the compression line *KG*. Then the valve immediately opens, as explained, to release the high steam which made this stroke. This steam expands against that in the receiver, which was compressed on the back stroke, giving the actual compression curve *GJ'* and expansion curve *FJ;* the pressures *EG* and *EF* meeting in a common pressure at *J'*. Then the *L*-cylinder starts again on the curve *III*, while the *H*-piston stands, and so on in repetition.

The valve movement is thus seen to be peculiar. Here, instead of the valves of one cylinder all moving simultaneously, and so with the other cylinder, they move in alternation. This will complicate the valve-gear somewhat.

It is to be observed that by this arrangement, the high steam is at once released from the *H*-cylinder on completion of stroke, so that it is available to the *L*-cylinder. Also, in the *L*-cylinder, the steam is retained while that piston stands, instead of being at once exhausted; the object being to keep this cylinder hot as possible.

Nature of the Expansion and Compression Lines.

The point of zero of volumes for the curves *HI* and *KGJ'* or *J*, is *A*, Fig. 9, while for *FJ*, or *FJ'*, it is *D*. The back pressure line of the *L*-cylinder is *QS*. The duplex point *JJ'* is due to the same causes here as in the first solution. In the union of volumes, the resulting pressure *BJ* or *J'* is regarded as very nearly the same as that found by drawing the two isodynamic lines *GJ* and *FJ;* isodynamic because of the absence of external work in the act of combining of pressures. But in the compression from *G*, work is done on the steam in the receiver, by the expanding steam from the *H*-cylinder, so that instead of the isodynamic *GJ* we will actually have the adiabatic *GJ'*, and the expansion curve of partial work *FJ'*. Heating accompanies the adiabatic compression *GJ'*, while in the expansion *FJ'* there will be cooling. In this way the different temperatures of *F* and *G* will approach a common point, but will probably not reach it until the end of the full commingling which follows the common pressure. Observing that *J'I* stands for the expanded volume of the high steam, the temperature of which is higher to some slight extent than that

in the receiver as compressed to J'; it appears that after the full commingling has taken place, and the temperatures become common, the point J' will have moved slightly toward I. This is on the supposition that J' is regarded as the point which divides the united volumes AD in such proportions that $J'I$ contains exactly the weight which was delivered by the expansion of FL.

Dryness of the Expanding Steam.

Respecting the dryness of the steam in the receiver, it appears that if FJ and GJ represent the equivalent of the actual process of combining, then the result at J will be a slight superheating. Now as the united volume expands adiabatically from I to II, there will probably be formed an appreciable amount of fog as supersaturating moisture. This will be exactly re-evaporated in the exact counter operation KJ', unless a portion of that moisture is precipitated to the bottom of the receiver as water, to collect into pools. In such event, it will not be so readily re-evaporated, and a considerable quantity of water may thus collect to be drawn off occasionally by a cock.

Insignificance of JJ'.

Similar reasoning may be applied to the discrepancy JJ', as was done in the first solution, to show that it is small. It will, therefore, be disregarded in the following analysis, KGJ' and III being regarded as adiabatic, and FJ' as isodynamic.

Area of Indicator Cards and General Equations.

The expressions (a) and (b) are suitable for the present case. Take

$$V_1 = Al$$
$$L_1 = \text{length } AE$$
$$L_2 = \text{length } AD$$

Then $P_1V_1 = P_1Al = \text{actual area } FEDL.$

$$L_2 = L_1 + l$$
$$\frac{l}{L_2} = \frac{V_1}{V_1 + V'}$$
$$\frac{P}{P_k} = \left(\frac{L_2}{x}\right)^a \qquad (36\tfrac{1}{3})$$

$$\text{Area } GEDK = AP_k L_2^a \int_{L}^{L_2} \frac{dx}{x^a}$$

$$= \frac{AP_k L_2^a}{1-a} \left\{ L_2^{1-a} - L_1^{1-a} \right\}$$

$$= \frac{AP_k L_2^a}{1-a} \left\{ L_2^{1-a} - (L_2 - l)^{1-a} \right\}$$

$$= P_k \frac{V_1 + V'}{a-1} \left\{ \left(1 + \frac{V_1}{V'}\right)^{a-1} - 1 \right\} \qquad (37)$$

The corresponding equation for the L-cylinder is obtained from (37) by putting $V_1 + V_2 + V'$, for $V_1 + V'$, and also $\frac{V_2}{V_1 + V'}$ for $\frac{V_1}{V'}$.

These equations become indeterminate when $a = 1$. To provide for this case expand $(L_2 - l)^{1-a}$ by the binomial formula, and the equation preceding (37) becomes

$$GEDK = AP_k l \left\{ 1 + \frac{a}{2} \frac{l}{L_2} + \frac{a(a+1)}{2.3} \frac{l^2}{L_2^2} + \&c., \right\} \qquad (d)$$

$$= P_k V_1 \left\{ 1 + \frac{a}{2} \frac{V_1}{V_1 + V'} + \frac{a(a+1)}{2.3} \left(\frac{V_1}{V_1 + V'}\right)^2 + \&c. \right\}$$

$$= P_k V_1 Q \qquad (38)$$

where for brevity we put for the series

$$Q = 1 + \frac{a}{2} \frac{V_1}{V_1 + V'} + \frac{a(a+1)}{2.3} \left(\frac{V_1}{V_1 + V'}\right)^2 + \frac{a(a+1)(a+2)}{2.3.4} \left(\frac{V_1}{V_1 + V'}\right)^3 + \&c. \qquad \text{(III)}$$

For the particular case that $a = 1$, the above integral becomes

$$(GEDK)_{a=1} = AP_k L_2 \, hyp.\, log. \frac{L_2}{L_1} \qquad (e)$$

$$P_k (V_1 + V') \, hyp.\, log. \left(1 + \frac{V_1}{V'}\right) \qquad (39)$$

in all of which P_k = the pressure $DK = CH$.

In a similar way we find for the area $IDCH$ of the large cylinder, by using equation (d) and assuming

$$Al = V_2 \text{ and } \frac{l}{L_2} = \frac{DC}{AC} = \frac{V_2}{V_1 + V_2 + V'}$$

$$IDCH = P_k V_2 \left\{ 1 + \frac{a}{2} \frac{V_2}{V_1 + V_2 + V'} + \right.$$

$$\left. \frac{a(a+1)}{2.3} \left(\frac{V_2}{V_1 + V_2 + V'} \right)^2 + \&c. \right\}$$

$$= P_k V_2 S \qquad (40)$$

where for brevity and convenience we put

$$S = 1 + \frac{a}{2} \frac{V_2}{V_1 + V_2 + V'} + \frac{a(a+1)}{2.3} \left(\frac{V_2}{V_1 + V_2 + V'} \right)^2 +$$

$$\frac{a(a+1)(a+2)}{2.3.4} \left(\frac{V_2}{V_1 + V_2 + V'} \right)^3 + \&c. \qquad (IV)$$

For the particular case that $a = 1$, (e) becomes

$$(IDCH)_{a=1} = P_k (V_1 + V_2 + V') \, hyp.log. \left(1 + \frac{V_2}{V_1 + V'} \right) \qquad (41)$$

Now the work done in the high-pressure cylinder will be

$$FGKL = P_1 V_1 - GEDK, \qquad (42)$$

and in the low-pressure cylinder it will be

$$IQSH = IDCH - P_3 V_2. \qquad (43)$$

For the engine working in continuity the work developed during a half cycle, or for one stroke of each cylinder, or by each high-pressure cylinder full of steam, will be the sum of (42) and (43), or

$$U = (P_1 V_1 - GEDK) + (IDCH - P_3 V_2)$$

$$= P_1 V_1 - P_k V_1 Q - P_3 V_2 + P_k V_2 S$$

$$= P_1 V_1 \left\{ 1 + \frac{P_k}{P_1} \left(\frac{V_2}{V_1} S - Q \right) - \frac{P_3 V_2}{P_1 V_1} \right\} \qquad (44)$$

and for $a = 1$

$$U' = P_1 V_1 \left\{ \begin{array}{l} 1 - \frac{P_k}{P_1}\left(1 + \frac{V'}{V_1}\right) hyp.\ log.\ \left(1 + \frac{V_1}{V'}\right) \\ - \frac{P_3 V_2}{P_1 V_1} + \frac{P_k}{P_1}\left(1 + \frac{V_2 + V'}{V_1}\right. hyp.\ log. \\ \left.\left(1 + \frac{V_2}{V_1 + V'}\right)\right. \end{array} \right\} \quad (45)$$

But in these equations p_k is as yet unknown. Regarding J and J' as coincident on the adiabatic KG produced, then from the proportionality of horizontal intercepts between adiabatics, we may write

$$\frac{HK}{IJ} = \frac{AC}{AD} = \frac{V_2 + V_1 + V'}{V_1 + V'} = 1 + \frac{V_2}{V_1 + V'} = \frac{V_2}{IJ}$$

$$= \frac{V_2}{IJ} = \left(\frac{P_1}{P_k}\right)^{\frac{1}{a}} = 1 + \frac{V_2}{V_1 + V'}.$$

Also,

$$\frac{P_1}{P_1} = \left(\frac{V_1}{IJ}\right)^n = \left(\frac{V_1}{V_2}\right)^n \left(1 + \frac{V_2}{V_1 + V'}\right)^n \quad (46)$$

Hence

$$\frac{P_1 P_k}{P_1 P_1} = \left(\frac{V_1}{V_2}\right)^n \left(1 + \frac{V_2}{V_1 + V'}\right)^{n-a} = \frac{P_k}{P_1} = \frac{P_2}{P_1} \quad (47)$$

This introduced in (44) gives in known terms the amount of work per high-pressure cylinder full of steam.

$$U = P_1 V_1 \left\{ 1 + \left(\frac{V_2}{V_1} S - Q\right)\left(\frac{V_1}{V_2}\right)^n \cdot \left(1 + \frac{V_2}{V_1 + V'}\right)^{n-a} - \frac{P_3 V_2}{P_1 P_1} \right\} \quad (48)$$

If $a = n$, the term $\left(1 + \frac{V_2}{V_1 + V'}\right)$ drops out. For a and $n = 1$,

$$U = P_1 V_1 \left\{ \begin{array}{l} 1 - \frac{V_1 + V'}{V_2} hyp.\ log.\ \left(1 + \frac{V_1}{V'}\right) \\ - \frac{P_3 V_2}{P_1 V_1} + \left(1 + \frac{V_1 + V'}{V_2} hyp.\ log.\left(1 + \frac{V_2}{V_1 + V'}\right.\right. \end{array} \right\} \quad (49)$$

If $V' = \infty$, and a and n as in (48), we get

$$U'' = P_1 V_1 \left\{ 1 - \left(\frac{V_1}{V_2}\right)^n + \left(\frac{V_1}{V_2}\right)^{n-1} - \frac{P_3 V_2}{P_1 V_1} \right\} \quad (50) \text{ or } (18)$$

the same as (18).

If $V' = \infty$, and a and $n = 1$, we get

$$U''' = P_1 V_1 \left\{ 2 - \frac{V_1}{V_2} - \frac{P_3 V_2}{P_1 V_1} \right\} \qquad (51) \text{ or } (19)$$

the same as (19).

The notation is the same as stated following (21) for P_1, P_3, V_1, V_2, and V'. Q and S stand for the infinite series given in (III) and (IV).

One fact to be observed particularly, in comparing these equations with those for the I solution, is the perfect agreement of the expressions for the work U as soon as V' is made infinite. This is evidently as it should be, since for an infinite volume of receiver it would not matter whether the high pressure exhausted into it immediately on completion of its stroke, or whether the exhaust were stayed each time during the half stroke; because the pressure could not vary appreciably in the infinite receiver during this time. For the infinite receiver it is only essential that equal weights be received from the high cylinder, and delivered to the low cylinder per stroke, the strokes being regarded as the same per minute for one as for the other cylinder.

The coincidence of the expressions for work, for the case of an infinite receiver, is therefore expected; and the fact of coincidence corroborates the analysis.

These equations (48) to (51) serve in calculations for duty where the whole work done for a period is compared with the coal consumed. In selecting the equation for use, judgment must be exercised as to the degree of approximation necessary in the case, and as to the proper values of a and n. Wet steam will require different values than dry, the value of a for such case being more properly m, as found in table (2).

Pressure at Different Points of Steam Action.

To determine the pressure of the steam at different points of action in the engine, we observe first that for $V' = \infty$, the pressures at H, I, J, and K, Fig. 9, become one and the same; that is to say, the pressure in the receiver remains constant, and the indicator diagrams for the two cylinders are simple rectangles.

For the pressure at I or J see Eq. (46).

For the pressure at H or K see Eq. (47), where $P_k = P_2$.

These give the initial and terminal pressures in the low cylinder, and the initial back pressure in the high cylinder. The terminal back pressure in the high cylinder is $P_g = EG$, for which, by aid of Fig. 9, we may write

$$\frac{P_g}{P_k} = \left(\frac{V_1 + V'}{V'}\right)^a = \left(1 + \frac{V_1}{V'}\right)^a.$$

Combining with (47),

$$\frac{P_g}{P_k}\cdot\frac{P_k}{P_1} = \left(1 + \frac{V_1}{V'}\right)^a \left(\frac{V_1}{V_2}\right)^n \left(1 + \frac{V_2}{V_1 + V'}\right)^{n-a} = \frac{P_g}{P_1}. \quad (52)$$

If $V' = \infty$, these equations, as well as (46) and (47), reduce to

$$\frac{P_g \text{ or } P_1 \text{ or } P_2}{P_1} = \left(\frac{V_1}{V_2}\right)^n \quad (53)$$

a common pressure, or a constant pressure of receiver, as above stated, for the case the receiver is infinite in volume. This equation also shows that n is the only exponent upon which the pressure of the infinite receiver depends. It also gives the pressure to which that of the receiver approaches as V' is made relatively very large.

The varying pressure at different points of stroke may be obtained by aid of (36½).

Equation (47) shows that if $a = n$, as it will nearly for wet steam, the pressure at H or K, $= P_2$, will be entirely independent of V' whether $V' = \infty$ or not. In this case the larger the receiver the greater will be the proportion of work done by the high cylinder, and the less by the low cylinder, as indicated by Fig. 9. The pressure P_2 is here the pivotal pressure.

It is a curious fact that for $a = n$, the so-called pivotal pressures, for both valve movements shown in Fig. 7, have one and the same value; as indicated by equations (15) and (47) for $a = n$. That is to say, for given initial pressures and ratio of cylinder volumes, the pressures of P_g of Fig. 8, and P_k of Fig. 9, are equal and constant, whatever the value of V'. Again, it is immaterial to this pressure whether $a = n$, or $V' = \infty$; and it is given by (24½) or (53), another evidence that for the infinite receiver the mode of operation of valves is unimportant, whether according to 1st or 2d of Fig. 7.

The ratio of equations thus:

$$\frac{(23)}{(47)} > 1$$

shows that the second valve movement results in a greater ratio of expansion than the first when V' is not infinite.

Relative Areas of Indicator Cards.

To find the relation between the amounts of work developed by the high-pressure cylinder and the low, we may take their ratio thus:

$$R = \frac{1 - Q\left(\frac{V_1}{V_2}\right)^n \cdot \left(1 + \frac{V_2}{V_1 + V'}\right)^{n-a}}{S\frac{V_2}{V_1}\left(\frac{V_1}{V_2}\right)^n \left(1 + \frac{V_2}{V_1 + V'}\right)^{n-a} - \frac{P_3 V_2}{P_1 V_1}} \tag{54}$$

For a and $n = 1$;

$$R' = \frac{1 - \frac{V_1 + V'}{V_2} \text{ hyp. log. } \left(1 + \frac{V_1}{V'}\right)}{\left(1 + \frac{V_1 + V'}{V_2}\right) \text{ hyp. log. } \left(1 + \frac{V_2}{V_1 + V'}\right) - \frac{P_3 V_2}{P_1 V_1}} \tag{55}$$

If $V' = \infty$, and a and n as in (54),

$$R'' = \frac{1 - \left(\frac{V_1}{V_2}\right)^n}{\left(\frac{V_1}{V_2}\right)^{n-1} - \frac{P_3 V_2}{P_1 V_1}} \tag{56}$$

If $V' = \infty$, and a and $n = 1$

$$R''' = \frac{1 - \frac{V_1}{V_2}}{1 - \frac{P_3 V_2}{P_1 V_1}} \tag{57}$$

Equations (56) and (57) are seen to be identical with (27) and (28), which is evidently correct for the infinite receiver.

Heat for Steam Production.

The heat required for making the steam is evidently the same here as in the first form of engine, or as given in equation (29).

Efficiency.

Hence we have the

$$\text{Efficiency} = \frac{U}{H}. \qquad (58)$$

For steam under given conditions, the denominator, H, is constant. Then evidently U will vary with the relative dimensions of V_1, V_2, or V'; and also with the values of a and n. The maximum value is therefore desirable.

Maximum Efficiency.

The maximum of (48) or (49) may be found by the same process as indicated for (16) or (17). The maximum of (50) is the same as for (18), because the equations are identical. Hence for U'' the conditions for a maximum are obtained from (31); also (32) follows for $n = 1$. Hence the maximum values of U''' and U''' for the present case are found in equations ($32\frac{1}{2}$) and (33).

But it is a remarkable fact that the maximum efficiency of this engine is exactly equal to that of the Woolf engine, without receiver, shown in Fig. 13, below. That is to say, when $a = n = m$, equation (61) below is the maximum of (48). This can be proved by using for the expression of the work, the same as (48) obtained by aid of (37), and the corresponding one for the L-cylinder; also (47); and finally the relations

$$\frac{V_2}{V_1} = \frac{V_1 + V'}{V'} = \frac{V_1 + V_2 + V'}{V_1 + V'},$$

obtained from Fig. 9, on the supposition that V' is made so small that the compression line KG is so raised that it extends from K direct to F. This compression line then becomes a cushion line, such that on the return stroke of the H-piston, the remaining steam is compressed and forced into the receiver until at the end of the return stroke the boiler pressure is just restored at F.

The size of the receiver for this special case is $V' = \frac{V_1^2}{V_2 - V_1}$; also the isodynamic expansion now vanishes so that this maximum is general.

Conditions for Equal Work of Cylinders.

That the cylinders do equal work, the numerator and denominator of (54) must equal each other, which condition gives

$$\frac{P_3 V_2}{P_1 V_1} = \left(Q + S\frac{V_2}{V_1}\right)\left(\frac{V_1}{V_2}\right)^n \left(1 + \frac{V_2}{V_1 + V'}\right)^{n-a} - 1, \qquad (59)$$

the solution of which may be proceeded with as suggested for (34).

If $V' = \infty$, this expression reduces to the same as (35), as it should; also to (36), for $n = 1$. This last is seen to be the same condition as for the maximum efficiency, for $V' = \infty$ and $n = 1$, as stated for the first engine, in which respect the engines agree.

The Infinitude of Possible Pump Movements.

In all the preceding cases the piston motion has been regarded as such that when one piston moves for making its complete stroke the other piston stands still at the end of its cylinder, and *vice versa*, as in the celebrated Worthington Pumping Engine. But compound pumping engines are in use in which we find the three parts, V_1, V_2, and V' as above, but with different piston and valve motions, as, for instance, in case of certain Cope & Maxwell pumping engines.

Respecting the possible variety of engines due to unlimited suppositions for piston motion, or valve motion, or both, it appears to be infinite. For almost any one of these, the diagrams corresponding with Fig. 8 or 9 become exceedingly difficult to delineate, except for the simple case $V' = \infty$. For instance, there might be the tarrying of the pistons, each for half or other fraction of its time; but with the relative period of strokes indifferent. The steam cylinders might be of equal volume, while one makes twice as many strokes as the other, and thus obtain expansion. This is admissible with or without tarrying of pistons. While the high piston tarries, its valve might open into the receiver at any point of time in the period of tarrying. And the low cylinder might close its valve from the receiver at any point in the tarrying of its piston. A comparatively simple case is that where the pistons do not tarry, and where the valves all work promptly on the termina-

tion of the strokes of their respective pistons. But here the periods of stroke of pistons might be in any given relation.

III. Strokes Co-initial and Co-terminal; without Tarrying.

To take an example of a simple case, let the pistons both make the same number of strokes per minute, and be so related that both begin and end their strokes together. For this case a little consideration will show that it matters not at which end of stroke one piston is, while the other starts at a particular end; because, for either one piston, the same changes occur at one end as at the other end of stroke. And let there be no tarrying, but both pistons moving continuously. For this, a little consideration will show that this engine may be rotative, with cranks at 180°, and one cylinder to each.

Complete Diagram and Indicator Cards.

Let Fig. 10 serve us for diagram of operations. The shaded areas are to be taken as the indicator diagrams; see footnote, p. 148. The volumes are as shown.

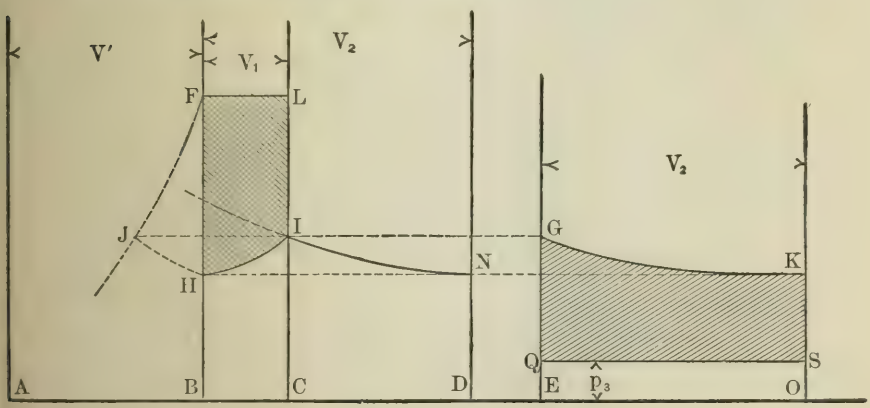


Fig. 10.

Now when the *H*-piston has terminated its stroke, let the back pressure from the receiver be *BH*, Fig. 10. As the valves of the *H* cylinder reverse, the exhaust raises the pressure by the commingling of the high steam *BF* with the receiver steam *BH*, with the resulting pressure as for the point *J*, equal *CI*. This new pressure is the initial back pressure for the *H*-pis-

ton, and the initial forward pressure for the L-piston for the next stroke. The volume of this steam includes that of the receiver and H-cylinder, or is equal $AC = V' + V_1$. The pistons now start and make their strokes together, the volume included increasing from AC to $AD = V' + V_2$, giving the expansion line IN drawn from A as the zero of volumes. Hence the pressure falls from CI to DN during the stroke of each piston, giving therefore the line III for the underside of the H-cylinder indicator card; and GK for the top line for the L-cylinder card. This latter card is drawn to one side to avoid confusing the figure.

We will not stop to recount the complete analysis for this.

For any case in practice, if the pressures at I and N, or H are known, the diagrams could be laid out on a drawing-board, and the areas measured with a planimeter. In this, to construct GK or IH from IN, it is only necessary to divide CD, BC, and EO into a certain number of equal parts, and draw horizontal lines from the points of intersection with IN. The corresponding points of intersection on IH and GK will be points in the curves required. IN is to be drawn from A as the origin of volumes.

For pressures we have,

$$\frac{P_i}{P_n} = \left(\frac{V_2 + V'}{V_1 + V'}\right)^a$$

$$\frac{P_1}{P_i} = \left(\frac{IJ}{V_1}\right)^n$$

$$\frac{P_n}{P_i} = \left(\frac{IJ}{V_2}\right)^a$$

whence

$$\frac{CL}{CI} = \frac{P_1}{P_i} = \left(\frac{V_2}{V_1}\,\frac{V_1 + V'}{V_2 + V'}\right)^n$$

$$\frac{CL}{DN} = \frac{P_1}{P_n} = \left(\frac{V_2}{V_1}\right)^n \left(\frac{V_2 + V'}{V_1 + V'}\right)^{a-n}$$

by aid of which the diagram can be accurately constructed.

For an infinite receiver $V' = \infty$; and the equations for pressures reduce to

$$\frac{P_1}{P_i} = \frac{P_1}{P_n} = \left(\frac{V_2}{V_1}\right)^n \tag{60}$$

which is the same as ($24\frac{1}{2}$) and (53) for this case of $V' = \infty$, which shows that, for the infinite volume of receiver, all these engines have the same efficiency. The same is true for $a = n$, making P_n the pivotal pressure.

The work performed by each high-pressure cylinder full of steam is readily obtained by aid of (37), and a comparison of Figs. 9, and 10. Thus we see that (37) gives the area *ICDN*, Fig. 10, if in (37) we change P_k to P_n; $V_1 + V'$ to $V_2 + V'$; and $\frac{V_1 + V'}{V'}$ to $\frac{V_2 + V'}{V_1 + V'}$; also, Fig. 10, the area $BIIIND =$ area *EGKO*. Hence the work per *H*-cylinder full of steam is *BFLIND*—$P_3 V_2$, or

$$U = P_1 V_1 + P_n \frac{V_2 + V'}{a - 1}\left(\left(\frac{V_2 + V'}{V_1 + V'}\right)^{a-n} - 1 \right) - P_3 V_2$$

and eliminating P_n

$$= P_1 V_1 \left\{ 1 + \left(\frac{V_1}{V_2}\right)^n \frac{V_2 + V'}{V_1(a-1)}\left(\left(\frac{V_2 + V'}{V_1 + V'}\right)^{a-1} - \right) - \frac{P_3 V_2}{P_1 V_1} \right\} \qquad \text{(f)}$$

If $V' = 0$ the receiver is dispensed with, and this case reduces to that of Fig. 13. The above, for $n = a$ then reduces to

$$U_1 = P_1 V_1 \left\{ \frac{a}{a-1} - \frac{1}{a-1}\left(\frac{V_1}{V_2}\right)^{a-1} - \frac{P_3 V_2}{P_1 V_1} \right\} \qquad (59\frac{1}{2})$$

which is the same as (61) if a is changed to m, as it should be for the present supposition of no isodynamic expansion nor consequent superheating. The change in diagram, Fig. 10, where $V' = 0$, is in the raising of the point I up to L. The diagram then agrees with Fig. 15, below.

As the volume of the receiver is changed from zero to infinity, the point I, Fig. 10, falls from L to the horizontal through N; while the point N remains stationary. To find the point I on a drawing-board for any set of values of V_1, V_2 and V'; first find N by aid of (60), then draw the adiabatic NI with the proper exponent, and with A for the zero of volumes.

We thus arrive at the important conclusion that by increasing the size of the receiver we diminish the amount of work performed by the same weight of steam, and to the extent due to the corresponding lowering of the line *NI*.

In the volume V' of receiver must be included all the space

about the valves and of the communicating pipes between the cylinders, as well as that in a receiver proper. Thus the superheating chambers sometimes employed between the cylinders must be counted in.

The effect of superheating in the receiver is to change the pressures and not the volumes. Such superheating simply raises the lines *NI* and *HI*. If the steam is dry without a superheater, then with it these lines will be raised nearly in proportion to the elevation of the absolute temperature by superheating.

IV. Strokes Interfluent, without Tarrying.

As an example of a case not quite so simple, and to show the effect of interruption due to the exhaust into the receiver from the high cylinder while the low cylinder is making its

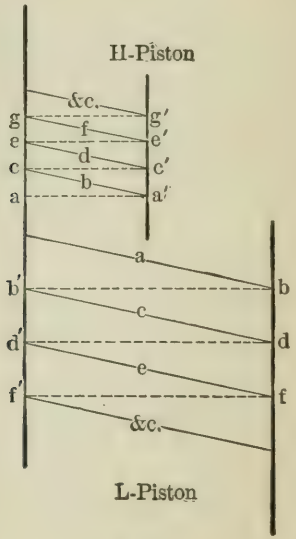


Fig. 11.

stroke, let the reversal of stroke for either piston be at the midstroke of the other. Then Fig. 11 may serve to indicate the relation between piston positions for continuity. The part *H* refers to the high cylinder, and *L* to the low. Now suppose *H* on the point of exhausting into the receiver, and let *a* represent the beginning and *a′* the end of this operation. This takes place at the midstroke, *a*, of the *L*-piston, as shown in

the L part of the diagram. As H exhausts, the increase of volume of receiver and connections will increase in the operation by an amount aa' on a proper scale. Now the H-piston travels from a' to b while the L-piston travels from a to b. Then the L-cylinder exhausts into the air or condenser, and its volume is cut off from the receiver to begin a new cylinder full. This volume cut off from the receiver is bb', as shown on the L part of the figure. This takes place at the midstroke b of the H-piston; see Fig. 11. And thus these operations continue, as can readily be traced from Fig. 11.

Now when a piston makes a half-stroke, the change of volume of the receiver and connections will not change by that amount alone, because two pistons are in action simultaneously, and the change of volume just referred to will be due to the combined movements of pistons, one of which (the H-) is compressing, and the other (the L-) is expanding this volume. We observe that the high piston *always* compresses, and the low expands this volume.

The letters a, b, c, d, etc., on Fig. 11, for any one letter denotes a single point of time, so that by referring to any single letter we can at once see the relative positions of both pistons. The stretches between a and a', c and c', etc., or b and b', d and d', etc., indicate shifting of action from end to end. Thus, when the exhaust is completed from one side of the H-piston, it immediately begins from the other side.

For the simultaneous positions, a, we see that the L-piston is at midstroke, while the H-piston is exhausting. Just before beginning the exhaust, a, the total volume in the receiver and connections is $V' + \frac{V_2}{2}$, and just after it is $V' + \frac{V_2}{2} + V_1$, as can easily be traced. For the point b, the H-piston is at midstroke, and the L-cylinder is on the point of exhausting and changing the volume from $V' + V_2 + \frac{V_1}{2}$ to $V' + \frac{V_1}{2}$, etc., etc. These changes of volume of receiver and connections are better shown in Fig. 12.

The Complete Diagram and Indicator Cards.

The shaded areas of Fig. 12 are the indicator cards for the cylinders. The volumes indicated show to which either card

belongs. All besides the shaded cards are construction lines used in obtaining the expansion lines and cards.

The lower part of the figure shows the variations in volume. $AB = V'$ is the volume of the receiver itself. At a we have

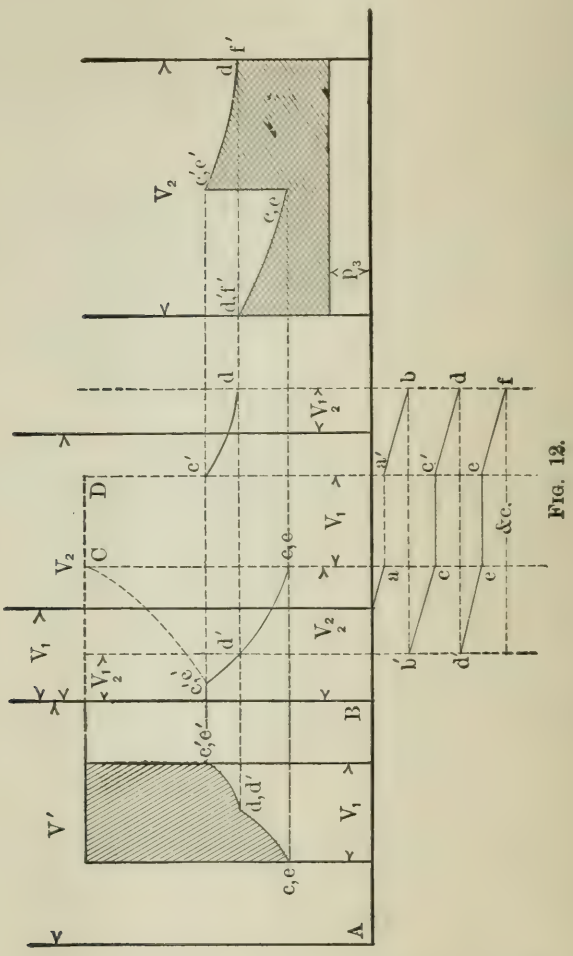


Fig. 12.

the L-piston at midstroke, while the volume in the receiver and connections is $V' + \frac{V_2}{2}$ as shown. Also the H-cylinder is ready to exhaust, and add the volume $aa' = V_1$. The line at $a'b$ is the variation of volume in the receiver and connections for the half-strokes shown for $a'b$ and ab in Fig. 11. Both pistons

move for this, one to reduce, and the other to enlarge the volume considered. The result is an enlargement to the point b, or to the volume $V' + V_2 + \frac{V_1}{2}$. Then the L-cylinder valves

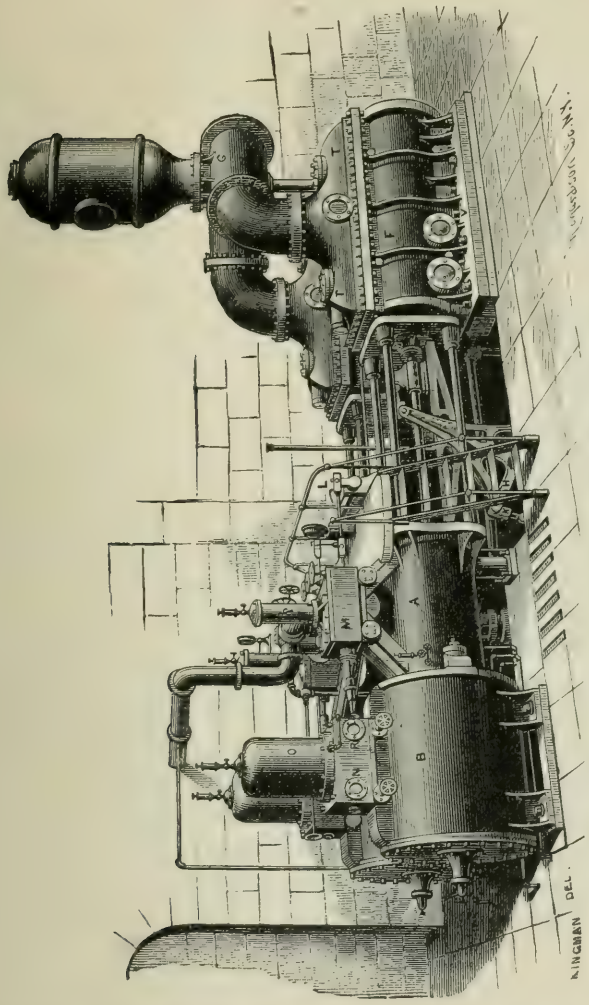


FIG. 13.—THE WOOLF TANDEM DUPLEX.

are reversed, and the volume $bb' = V_2$ is cut off, leaving only $V' + \frac{V_1}{2}$. The volume $b'c$ is due to combined two half-strokes similarly as in $a'b$. Then cc' is like aa', etc.

Now the expansion line for the change of volume $a'b$, or $c'd$,

etc., is $c'd$ above, in the upper part of Fig. 12. This is drawn from A as the zero of volumes. Also the expansion line for $b'c$, or $d'e$, etc., is $d'e$ above. For this the zero is also at A. When the H-cylinder exhausts into the receiver and connections, the volume is raised from $V' + \frac{V_2}{2}$ to $V' + \frac{V_2}{2} + V_1$, or from C' to D; the steam following from a high-pressure point, C, giving the expansion line Ce', the latter meeting the compression line $cd'c'$ as shown. The resulting pressure is that for the point e'. The expansion from C is for a zero of volumes at D, as will be understood after studying Figs. 8 and 9.

The diagrams are drawn at one side and the other, to avoid confusing the figure.

Now as the H-cylinder exhausts, the pressure becomes that at c', when the H-piston begins its back stroke with a like back pressure. Owing to an increase of volume during this back stroke, the line that would be a compression line for this cylinder alone, becomes a falling or expansion line as shown; first, as far as to d while the L-piston makes a half-stroke; and then as continued to c for the other half, but with a diminishing volume in the receiver and connections. Hence, the lower line $c'de$ of the H-cylinder card is a broken line as shown.

The L-cylinder expansion line is in two parts also, that at $d'e$ being due to the fall of pressure for the first half of stroke as traceable by lettering. At the midstroke there is a sudden rise of pressure ee', due to the exhaust of the H-cylinder into the receiver. From this point expansion continues on a new line due to a different pressure and volume.

Without entering into analysis, it is probably safe to predict that for an infinite volume the pressure in the receiver will be the same as by (60) and other equations; that is to say, the efficiency is still the same as previously given for an infinite receiver, and nearly so for receivers relatively large. Hence, when the receiver is very large as compared with the cylinders, and when there is no cut-off to either cylinder, the efficiency of engine remains very nearly the same, irrespective of the piston motion or valve motion. Whether there be an advantage in any form of valve or piston motion, for a finite receiver over the infinite, will perhaps be best shown by the numerical results subsequently given.

For the large receiver it is evident that expansion may be

obtained equally well, either with equal strokes and unequal cylinders, or unequal strokes with equal cylinders, or both combined.

In these discussions the engine itself is the only part of the machine brought into account, but in the practice of steam-pump engineering there are essential considerations relative to the pump as well, some of which have already been referred to.

V. The Tandem Duplex Compound Engine.

This engine differs essentially from the preceding by having four cylinders and no receiver.

Such an engine is shown in Fig. 13, in which there are four

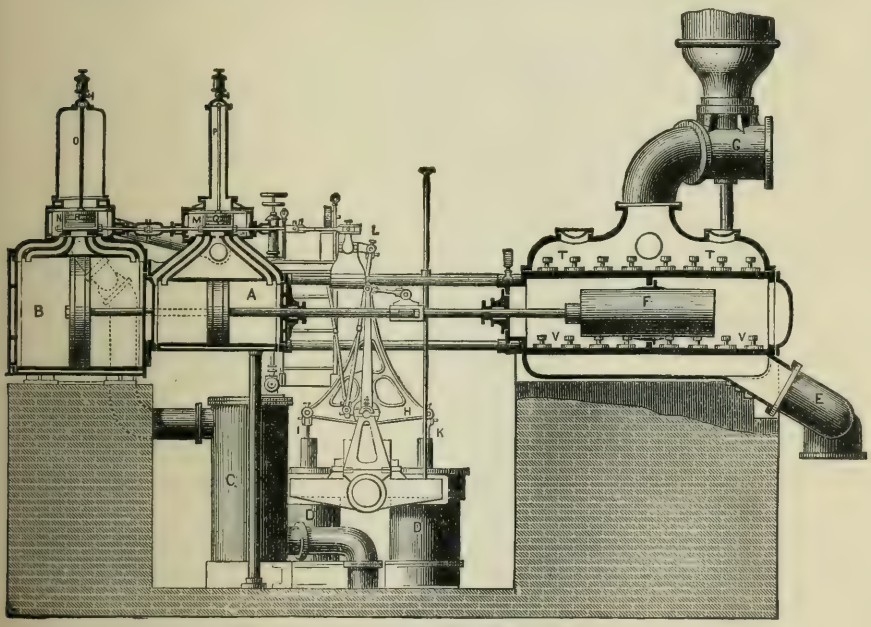


Fig. 14.—Showing Fig. 13 in Section.

steam cylinders, two of one size and two of another size ; one large and one small cylinder are seen arranged in line of each one of the two piston-rods. The two on one piston-rod form one complete engine on the Woolf form.

Fig. 14 is a sectional view of the same engine, showing the relation of parts and the differing sizes of cylinders. The condenser is situated below.

Thermodynamically, however, it might be as well treated without the consideration of duplex, because in reality there are two distinct engines in this form of duplex. We will treat one part as covering the whole in principle.

Here one cylinder may be placed in line with the other, on a common piston-rod, and when so related the arrangement is called "tandem." But the arrangement is immaterial, provided the strokes are co-terminous and without tarrying. The steam is to be delivered directly from the high-pressure cylinder into the low, without the intervention of the receiver. Also, here the steam is supposed to be admitted to the *H*-cylinder for the full stroke, and full pressure of boiler; it is then to be exhausted, or transferred to the other cylinder during the whole stroke, which stroke is in common for the two pistons. In this way the volume of steam which occupies the *H*-cylinder at the end of one stroke, is expanded to the volume of the *L*-cylinder by the end of the next stroke.

If, as before, V_1 = the volume of the *H*-cylinder, and V_2 that of the *L*-cylinder, we will have the ratio of expansion,

$$r = \frac{V_2}{V_1}.$$

The diagram for this case is shown in Fig. 15, with volumes and pressures indicated; also the indicator cards with shaded areas, the cards being drawn to the same scale of volumes.

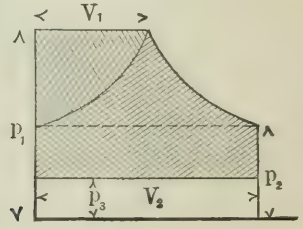


FIG. 15.

The formula for this case is well known. For each high-pressure cylinder full of steam the energy exerted, according to Rankine, is

$$U_1 = (P_m - P_3)\, V_2$$

where

$$P_m = P_1 \left(\frac{i r^{i-1} - r^{-i}}{i - 1} \right)$$

where $i = m$ of table (2). Combining, we obtain

$$U_1 = P_1 V_1 \left\{ \frac{m}{m-1} - \frac{1}{m-1}\left(\frac{V_1}{V_2}\right)^{m-1} - \frac{P_3 V_2}{P_1 V_1} \right\} \quad (61)$$

The efficiency is, as before,

$$\text{Efficiency} = \frac{U_1}{H}. \quad (62)$$

The relation between the volumes and terminal and initial pressures is

$$\frac{P_1}{P_2} = \left(\frac{V_2}{V_1}\right)^m. \quad (63)$$

The effect of passage spaces between the cylinders has been considered under the III solution, where it is represented by V'_1, great or small, including all space between valves in the passages, superheaters, etc.

In all the above solutions put V_1 for the sp. vol. in calculations for 1 lb.

Numerical Results for Comparison.

A few results have been computed and collected in the following table:

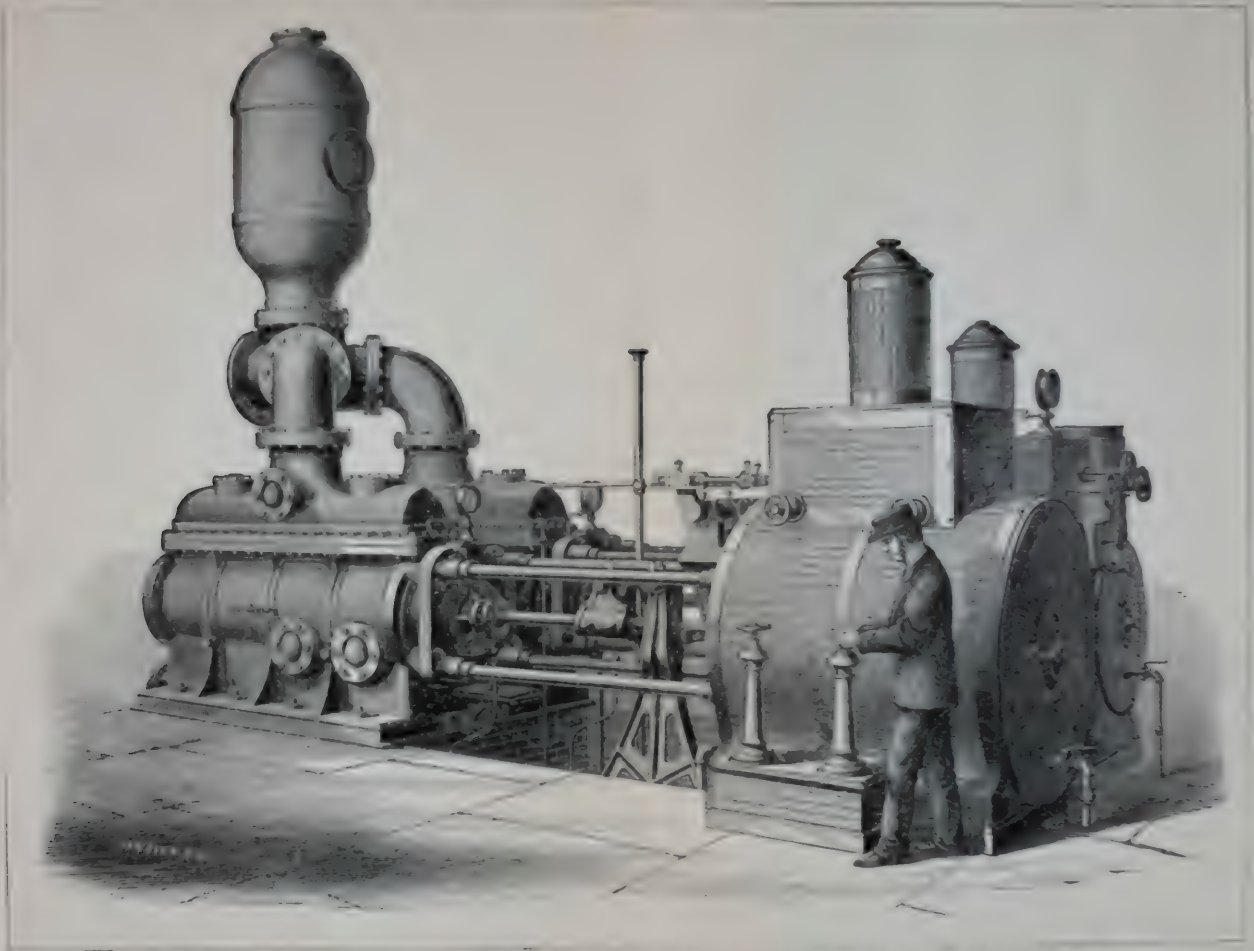
For the first column (16) was used, and for the second (48); that is, the complete formulas were put to the test.

The feed-water was assumed at the temperature 149° F., and the back pressure 3.62 pounds per square inch, absolute.

The exponent a was taken at $\frac{4}{3} = 1.3333$, n at 1.0456, and for the tandem engine, m was taken at 1.135. The value of a is probably too high for ordinary practice where steam is likely to be supersaturated; probably the best value for practice lies between 1.1 and 1.2.

Table of Results for the I, II, and V Cases.

P_1	$\frac{P_1}{P_3}$	$\frac{V_2}{V_1}$	*Effy.* I $V' = 2V_2$	*Effy.* II $V' = 2V_2$	*Effy.* $V' = \infty$, and Max. of I.	*Effy.* $V' = \infty$, $n = 1$, and Max. of I.	*Effy.* Tandem and Max. of II.	Work in V_1 / Work in V_2				Pressure of admission, P_1 / Pressure of exhaust, P_2			
								I	II	$V' = \infty$.	$V' = \infty$, $n = 1$.	I	II	$V' = \infty$.	Tandem
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
15.60	4.31	2	.0597	.0790	.0718	.0700	.0842	1.77	.78	1.01	1.	1.96	2.27	2.08	2.17
37.68	10.41	3	.0824	.1055	.0968	.0962	.1238	1.51	.86	1.03	1.	3.03	3.45	3.13	3.45
71.49	19.75	4	.0974	.1230	.1126	.1114	.1547	1.47	.83	1.04	1.	4.17	4.76	4.35	4.76
119.2	32.91	5	.1060	.1326	.1217	.1213	.1755	1.47	.90	1.05	1.	5.26	5.88	5.26	6.25



THE TANK COMPOUND ENGINE WITH UNEQUAL CYLINDERS

In looking over the table we at once notice the glaring fact that the tandem engine excels all the others in efficiency, and by a considerable percentage. At 23 pounds per square inch apparent pressure, the excess of efficiency of the tandem over the II, is about 17 per cent. of the efficiency of the latter. For 104 pounds per square inch apparent pressure, the same is about 32 per cent.

A second important fact respecting the two valve movements, viz., that of the I and II, is that the latter is a high percentage above the other.

A third important fact appearing in the table, is that in the II movement, the efficiency is a very considerable percentage greater when the receiver is small than when it is infinite, a fact in support of the conclusions of solutions of II and III. Compare columns 5 and 6. For the 5, the receiver is only twice as large as the low-pressure cylinder, and yet the efficiency here is from 8 to 10 per cent. higher than for the engine with an infinite volume.

For I, however, the case is the reverse, but in a greater ratio; that is to say, the efficiency is lowered from 13 to 17 per cent., by changing the receiver from an infinite volume to one only twice as large as the low-pressure cylinder.

As to the value of n, it appears that the efficiency does not change materially when n changes from 1 to 1.0456.

LXV.

THE SPECIFIC HEAT OF PLATINUM AND THE USE OF THIS METAL IN THE PYROMETER.

BY

J. C. HOADLEY, BOSTON, MASS.

In a paper which I had the honor to present to the American Society of Mechanical Engineers at the meeting held at Hartford in May, 1881, I gave, as the best estimate of the mean specific heat of platinum which I was able to form—based on the data to be found in Clark's "Constants of Nature"—0.0333, equal to one-thirtieth of the specific heat of water under standard conditions; and apparently uniform, or nearly

so, at all temperatures ordinarily attainable. At the same time I stated that a careful study of the original memoirs might disclose such reasons for assigning greater weight to the results obtained by some experimenters than to the varying results obtained by others, as to lead to a probable mean result much more trustworthy than that of my first crude approximations.

Such a study of the original memoirs, and a careful discussion of the several experiments therein described, for which I had neither the requisite facilities nor the necessary leisure, was made during his summer vacation by Mr. Silas W. Holman, Instructor in Physics at the Massachusetts Institute of Technology, who generously placed at my disposal the interesting and valuable fruits of his labors.

Mr. Holman first clearly points out the distinction between the terms "true specific heat" and "mean specific heat." The *true* specific heat of any substance at $t°$, is the amount of heat, expressed in heat units, required to raise the unit weight of the substance from any temperature $t°$ to $t° + 1°$, or more properly from $t°$ to $t° + dt$, whence we may write the true specific heat at $t° = \frac{dh}{dt}$ = first differential coefficient of the heat with regard to the temperature (of course not passing through change of state, as from solid to liquid, or from liquid to gaseous).

On the other hand, the *mean* specific heat from $0°$ to $t°$ is the amount of heat, expressed in heat units, required to raise the unit of weight from $0°$ to $t°$, divided by the number of degrees of this temperature $t°$, $0°$ in this case being $0°$ C. For Fahrenheit degrees the equivalent expression is the amount of heat required to raise the unit weight from $32°$ to $t°$, divided by the number of degrees embraced between $32°$ and $t°$.

Confining ourselves, for the sake of simplicity, to Centigrade degrees, for the present, let h_t, h_{t1}, etc., = number of heat units required to raise unit weight from $0°$ to $t°$, $t_1°$, etc., respectively. Then let $\frac{h^t}{t}$ $\frac{h_{t1}}{t_1}$, etc., = mean specific heat from $0°$ to $t°$, $t_1°$, etc., respectively. Also, $h_{t1} - h_t$ = number of heat units required from $t°$ to $t_1°$. Then $\frac{h_{t1} - h_t}{t_1 - t}$ = m. sp. ht. from $t°$ to

$t_1°$. Now $h_t = t(a + bt + ct^2 + \ldots$ etc.), and $h_{t1} = t_1(a + bt_1 + ct_1^2 + \ldots$ etc.),

$\therefore h_{t1} - h_t = a(t_1 - t) + b(t_1^2 - t^2) + c(t_1^3 - t^3) + \ldots$ etc.

$\therefore \dfrac{h_{t1} - h_t}{t_1 - t} = a + b(t_1 - t) + c(t_1^2 - 2tt_t + t^3) + d(\ldots$ etc.)

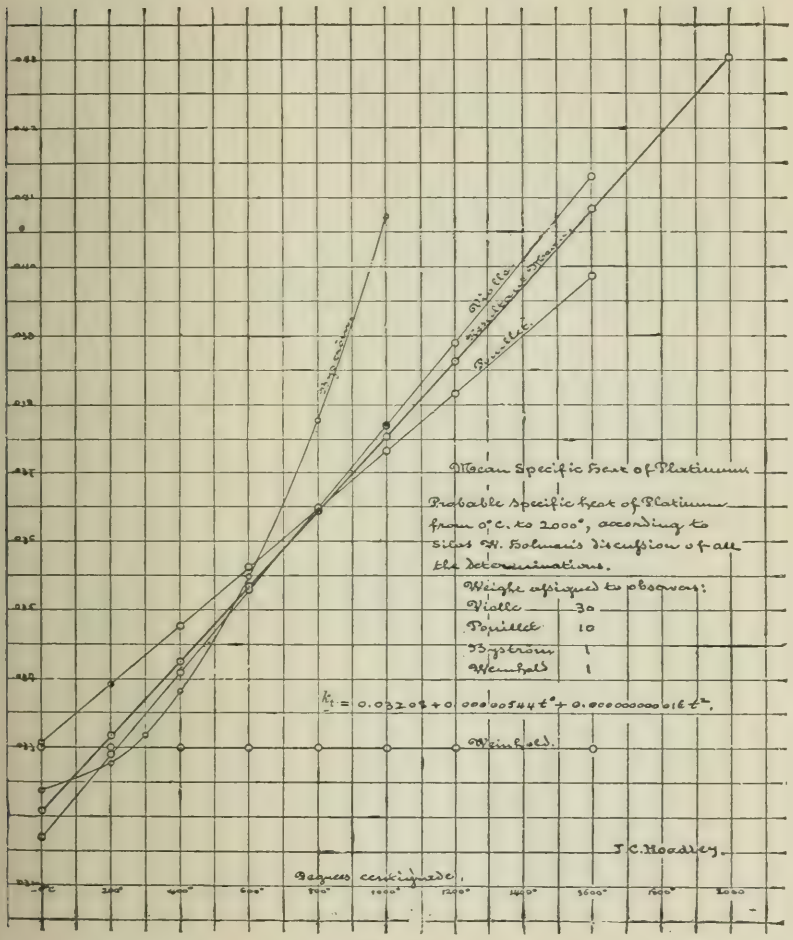

Mean Specific Heat of Platinum.
Probable Specific Heat of Platinum from 0° C. to 2000°, according to Sirs W. Holman's discussion of all the determinations.
Weights affixed to observations:
Violle 30
Pouillet 10
Bystrom 1
Wcinhold 1
$k_t = 0.03208 + 0.000005444t° + 0.000000000616t^2$.
Weinhold.
J. C. Hoadley.
Degrees centigrade.

FIG. 17.

which, at the limit when t_1 approaches t, becomes the *true* specific heat at $t° = \dfrac{dh}{dt} = a + 2bt + 3ct^2 + 4dt^3 + \ldots$ etc., while the *mean* specific heat from 0° to $t° = \dfrac{h_t}{t} = a + bt + ct^2 + dt^3 + \ldots$ etc.

The neglect of this obvious distinction, and the confusion of *mean* with *true* specific heat, vitiated my work. The location of points on my diagram, representing mean specific heat determinations at points midway between the two extremes for which the determinations were made, was erroneous and confusing. For instance, the determination 0.03818, for the mean specific heat 0° to 1200 C., should have been located at 1200° on my diagram, instead of at 600°, as I located it.

Mr. Holman also introduces Violle's results for the specific heat of platinum which he considers the best results by far which we possess.

In discussing the results Mr. Holman remarks, as I had already done, that every observer has found for platinum an increase of specific heat with increase of temperature, and that the *rates* of increase found by the various observers are not very diverse. In the expression $\frac{h_t}{t} = a + bt + ct^2 + dt^3 +$ etc., we wish to find the most probable values of the constants, a, b, c, d, etc., up to a limiting temperature, $t =$, let us say, 1600° C. Now, of these constants a is the *true* specific heat 0° C. To obtain this, we may, if we choose, collect all observations at this temperature, and, giving proper weight to each, take the mean, this constant being entirely independent of the others. Mr. Holman has chosen another method, by which, however, he has arrived at almost identically the same results which the above method would have given.

Taking each trustworthy set of observations, he has found, by the graphical method, or by the method of least squares, the value of a, b, and c, for that set, if the experimenter has not done so himself. Then calculating for a series of temperatures sufficiently near together—at intervals of 200° C. up to 1600° C., the mean specific heat for that temperature—and assigning to each set its proper weight, as nearly as may be, he takes a mean of each column.

From these means may be immediately calculated the values of a, b, and c. Higher powers than the square of t are useless in the present state of our knowledge, and even that may be discarded in the case of platinum; but it must be retained in the case of all other substances.

But if we prefer a value of a deduced from more observations, or from any particular set of low temperature obser-

vations, we can introduce such value without affecting the accuracy of the values of b and c. Mr. Holman gives in a table, which I reproduce, a summary of his interesting and valuable labor on platinum, and, further on, a summary of the results of various observers. To Violle he gives a weight of 30, as his determinations have the widest range (except Pouillet's, which have the same range), and are, in Mr. Holman's opinion, by far the most thorough, careful, and accurate, Violle being a skilful observer. To Pouillet's determinations Mr. Holman assigns a weight of 10, as having the same range as Violle's, but without the advantage of all the facilities for accurate work possessed by the latter. Byström's results are apparently pretty good, but extend only to 300° C., and are therefore entitled to but little weight when extrapolated to 1600° C.

Weinhold's results have not equal concordance among themselves, nor do they appear to have been made with the same degree of care and skill as even Pouillet's.

To Byström's and Weinhold's determinations, which he considers of little value, Mr. Holman assigns a weight of one each.

In all cases it will be noted that the temperatures are upon the air thermometer.

Mean Specific Heat of Platinum from 0° to t° C.

Observer.	Wt.	$t°=0°$	200°	400°	600°	800°	1000°	1200°	1600°
Violle, . . .	30	.0317	.0329	.0341	.0353	.0365	.0377	.0389	.0413
Pouillet, . .	10	.03307	.03392	.03477	.03562	.03649	.03732	.03817	.03987
Byström, . .	1	.03239	.03278	.03381	.03547	.03778	.04073	.04431	.05341
Weinhold, .	1	.0330	.0330	.0330	.0330	.0330	.0330	.0330	.0330
Means, . . .		.03208	.03315	.03423	.03533	.03645	.03758	.03871	.04105

From the above means Mr. Holman deduces approximations which he considers sufficiently exact as the mean specific heat from 0° to $t°$, $k_t = 0.03208 + 0.00000544t° + 0.000000000016t^2$, or, if ct^2 be dropped, $k_t = 0.03208 + 0.00000547t$, for platinum.

It will be observed that when the third term, ct^2, is omitted, Mr. Holman's curve, when represented graphically, becomes a

straight line, and that the eighth decimal in the constant b becomes 7 instead of 4.

Mr. Holman deduces in a similar manner, but with less exactness, on account of the paucity of material, the probable mean specific heat of iron from 0° C. to 300°, 600°, and 1000° C., as exhibited in the subjoined table :

Mean Specific Heat of Iron from 0° to t° C.

Observer.	Wt.	t = 0° C.	300°	600°	1000°
Weinhold, ...	5	.10591	.13150	.16907	.2378
Bède, ...	3	.1053	.1266	.1479	.1763
Byström, ...	2	.11164	.11703	.13100	.1629
Means, ...		.10687	.12714	.15510	.2044

From these means is deduced the following equation for the mean specific heat of iron :

$$k_t = 0.10687 + 0.0000547t + 0.0000000428t^2.$$

In this expression, the third term, ct^2, cannot be neglected ; the line is distinctly a curve. These constants are in all cases for Centigrade degrees, and must be multiplied by $\frac{5}{9}$ to reduce them for Fahrenheit degrees. Performing this multiplication, the expressions become, in Fahrenheit degrees :

For the mean specific heat of platinum, from 32° to t° F. :

$$k_t = 0.03208 + 0.000003033\ (t - 32) + 0.000000000009\ (t - 32)$$

or, omitting the last term, as we may safely do, for platinum :

$$k_t = 0.03208 + 0.0000034\ (t° - 32).$$

For the mean specific heat of iron, from 32° to t° F. :

$$k_t = 0.10687 + 0.0000304\ (t - 32) + 0.0000000238\ (t - 32)^2.$$

For pyrometric purposes, iron and all other metals save platinum may be left out of consideration. For platinum, my assumption of $.0333 = \frac{1}{30}$, as the uniform specific heat at all ordinary temperatures, is found to be correct only at a certain

temperature, namely, 446.195° Fahr., equal to 230.108° C. At all temperatures below this, my assumption, 0.333, is too high; at all higher temperatures, it is too low.

The rate at which the mean specific heat changes is, per degree F., 0.00000304 deg.

For the 32° F. between 0° F. and 0° C., the difference in m. sp. h. is $32 \times 0.00000304 = 0.00009728$, and this difference subtracted from the mean sp. h. of Pt. at 0° C. will give the m. sp. h. of Pt. at 0° F. thus: $0.03208 - 0.00009728 = 0.03198272$.

Of course we may substitute this value of the first term, a, this number, .031983 (specific heat of platinum at 0° F.), for the number in the table, 0.03208 (sp. ht. of Pt. at 32° F.), when $t°$ will be the temperature F. from 0° F., and the 32° must not be subtracted from t.

The assumption, 0.0333, for the first approximation in proportioning the pyrometer, is a very convenient one. Quite correct for the temperature indicated by 446.195° F. = 230.108° C., which is about the upper limit of accurate indication by the mercurial thermometer, the corrections to be applied from this point upward are all in the same direction, all *minus*. For example, 1050.4° observed, = 1000° corrected; 2022.4° observed, = 1800° corrected.

The subjoined table has been computed for the Fahrenheit scale and zero, by the use of the formula

$k_t = 0.031983 + 0.000003022\ (t - 32) + 0.000000000009\ (t - 32)^2$.

The corrections *below* 446.195° are *plus*.

The lines 32° and 212° are inserted for convenience in testing the pyrometer for verification. At 32° true temperature the indicated temperature is 30.8°, a correction of + 1.2°. At 212°, or the boiling-point, the indicated temperature is 207.5°, a correction of + 4.5°. In my pyrometer the water and so much of the metal as shares its temperatures being together equal to 2 lbs. of water, and the platinum ball being 0.6 lb., and the assumed sp. ht. $\frac{1}{30}$ that of cold water, the assumed ratio is 100 to 1; and with good thermometers having about 0.8 in. to 1° – graduated to 0.1°, on which $\frac{1}{40}$ or even $\frac{1}{50}$ of a degree can be accurately read, the greatest error need not exceed 6°. By skilful manipulation, error is nearly eliminated.

It will be observed that the table is carried up to 4000° F., the reputed melting-point of platinum.

Temperatures, in deg. Fahr., corresponding with specific heat in column 2.	Mean sp. ht. of platinum, computed for each 100 deg. Fahrenheit.	Differences of sp. ht. per each 100° Fahrenheit.	Ratio of computed to assumed sp. ht., viz. : $\frac{1}{30}$ water = 0.033333.	Differences of ratios for each 100° Fahrenheit.	Observed loss of temperatures by platinum at assumed ratio of sp. ht., 30 to 1.	Differences of observed temperatures per 100° Fahrenheit.
1	2	3	4	5	6	7
0	.031983		.95950		0.0	
		303		907		96.9
32	.032080		.96240		30.8	
		302		907		98.6
100	.032286		.96857		96.9	
		302		908		100.5
200	.032588		.97764		195.5	
		303		908		100.5
212	.032624		.97783		207.5	
		302		908		102.3
300	.032891		.98672		296	
		302		908		102.3
400	.033193		.98580		398.3	
		303		909		104.1
446.195	.033333		1.00000		446.2	
		304		910		106
500	.033496		1.00489		502.4	
		303		910		107.8
600	.033800		1.01399		608.4	
		303		910		109.6
700	.034103		1.02309		716.2	
		304		911		111.4
800	.034406		1.03219		825.8	
		304		912		113.2
900	.034710		1.04130		937.2	
		304		912		115.1
1000	.035014		1.05042		1050.4	
		304		913		116.9
1100	.035318		1.05954		1165.5	
		305		913		118.7
1200	.035622		1.06867		1282.4	
		304		914		120.6
1300	.035927		1.07780		1401.1	
		305		914		122.4
1400	.036231		1.08694		1521.7	
		305		915		124.3
1500	.036536		1.09608		1644.1	
		305		915		126.1
1600	.036841		1.10523		1768.4	
		305		916		127.9
1700	.037146		1.11438		1894.5	
		306		917		129.7
1800	.037451		1.12354		2022.4	

Temperatures in deg. Fahr., corresponding with specific heat in column 2.	Mean sp. ht. of platinum, computed for each 100 deg. Fahrenheit.	Differences of sp. ht. per each 100° Fahrenheit.	Ratio of computed to assumed sp. ht., viz. : $\frac{1}{30}$ water = 0.033333.	Differences of ratios for each 100° Fahrenheit.	Observed loss of temperatures by platinum at assumed ratio of sp. ht., 30 to 1.	Differences of observed temperature per 100° Fahrenheit.
1	2	3	4	5	6	7
1900	.037757		1.13271		2152.1	
		306		917		131.7
2000	.038063		1.14188		2283.8	
		305		917		133.4
2100	.038368		1.15105		2417.2	
		306		918		135.3
2200	.038674		1.16023		2552.5	
		307		919		137.2
2300	.038981		1.16942		2689.7	
		306		919		139.0
2400	.039287		1.17861		2828.7	
		307		920		140.8
2500	.039594		1.18781		2969.5	
		306		920		142.7
2600	.039900		1.19701		3112.2	
		307		921		144.6
2700	.040207		1.20622		3256.8	
		307		921		146.4
2800	.040514		1.21543		3403.2	
		308		922		148.3
2900	.040822		1.22465		3551.5	
		307		923		150.1
3000	.041129		1.23388		3701.6	
		308		923		152.0
3100	.041437		1.24311		3853.6	
		308		923		153.9
3200	.041745		1.25234		4007.5	
		308		924		155.7
3300	.042053		1.26158		4163.2	
		308		925		157.6
3400	.042361		1.27083		4320.8	
		308		925		159.5
3500	.042669		1.28008		4480.3	
		309		926		161.3
3600	.042978		1.28934		4641.6	
		309		926		163.2
3700	.043287		1.29860		4804.8	
		309		927		165.1
3800	.043596		1.30787		4969.9	
		309		927		166.9
3900	.043905		1.31714		5136.8	
		309		928		168.8
4000	.044214		1.22642		5305.6	

Since the highest temperature at which the sp. ht. of platinum has been determined is 1200° C. = 2182° F., all the numbers in the table above 2200° must be received with a certain degree of gradually increasing reserve; and the analogy of other metals leads us to suppose that between 3000° and 4000° the specific heat may rise more rapidly than the formula indicates There can be no great error up to 3000°, and between that limit and 4000° it can only be said that the figures here given are the best attainable, and if of little practical use are better than none.

Note.—From the observed loss of temperature in column 6, find the corresponding *true* loss, in column 1, and to this add the temperature of the water in pyrometer after the immersion of the platinum, to obtain the true temperature of the platinum at immersion.

This method of using the table gives a result slightly in excess of the true temperature, usually 0.5 per cent. to 1 per cent., depending on the temperature of the *water* after the immersion of the platinum.

To give *exact* results, the table should be calculated for mean sp. ht. from the final temperature of the water (after immersion), instead of from 32° F., to the several upper limits, varying by 100° up to 4000°.

This would be impracticable without a separate table for each temperature, varying by 1°, or by a small number of degrees, within the range of the initial and final temperature of the water, say 40° to 100°.

By adding the final temperature of the water, after immersion, to the loss of heat by the platinum heat-carrier, in *Pyrometer* degrees (*i. e.*, the product of the rise of t, of the water in degrees F., or more exactly, the increase in British thermal units—multiplied by the ratio of the heat-capacity of the water to the assumed heat-capacity of the platinum heat-carrier, 100 to 1, normally), and finding in column 6, by the aid of the differences in column 7, the corresponding number, the number opposite in column 1 will be *very nearly* the true temperature of the heat-carrier at the instant of its immersion.

Added since the Meeting.

A closer approximation may generally be made, by adding to the product of the rise of temperature of the water or of heat in British thermal units, multiplied by the ratio of the heat-capacity of the water to the assumed heat-capacity of the heat-carrier, the temperature of the water after immersion; then finding the corresponding number in column 6 by the aid of the differences in column 7, and taking the number opposite in column 1. The temperature so found will rarely differ from that worked out by the formula by more than 0.1 of *one per cent.* J. C. H.

LXVI.

CHRONOGRAPH FOR ENGINEERING PURPOSES, WITH THE HIPP ESCAPEMENT.

BY

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HAVING for a number of years felt the need of some instrument for measuring and recording the velocity of pumping machinery with which I have been brought in contact professionally at the deep mines on the Comstock Lode, where the irregularities due to long and heavy pump-rods, as well as other masses in motion, were greatly felt, I was forcibly impressed with an article by Robert Briggs, C.E. (*Journal Franklin Institute*, 1877, page 89), describing the "Hipp Escapement" and its adaptability to the purposes I desired.

I corresponded with that gentleman, and he had constructed for me, in Philadelphia, the escapement and driving-gear now used (for a detailed account of the Hipp escapement I must refer to his paper on that subject); but the revolving drum and other arranged parts of the instrument had to be changed, as no way of recording the curves of motion on paper could be used that produced perceptible friction (such as pencils or ink); and on account of the exceeding sensitiveness of the controlling spring of the escapement, great care was required in securing a perfect balance of the revolving drums with ease of motion, without the use of heavy driving weights; in other words, all parts of the instrument had to be made as sensitive

as possible, so as to require the least possible weights to produce the desired motion.

In the start numerous failures had to be put up with from not paying attention to these points of construction, and even now, if the recording paper is not properly put on the revolving drum, a slight excess of weight on one side of the drum, such as that due to lapping the paper, will produce a perceptible change of sound from the escapement-spring, indicating an acceleration or retardation of motion, according as the excess is on the descending or ascending side of the drum. In covering the drum with paper I have found it desirable to cut the sheets some $\frac{3}{8}$ or $\frac{1}{4}$ inch less than the exact circumference of the drum, and to unite the edges by means of a strip of paper, mucilaged and lapping slightly on each edge. The whole joint is then thinned down with fine sandpaper to equal weight and smoothness; the whole sheet is covered with a coating of lampblack from a suitable hand-lamp, and is then ready to receive the curve of motion.

The tracers, both for recording seconds as well as the velocity curve of the engine, are made of flat strips of spring steel, the axis of each being pivoted at the end on adjustable screw-centres, to prevent loss of motion. By means of a small steel wire and weight extending to the opposite side, the tracers can be made to bear as lightly as desirable on the paper, and, when properly adjusted, the pressure is only sufficient to remove the lampblack without touching the paper, thereby leaving a fine white line on the dark background with the least possible interruption of motion. The whole is permanently set by dipping the face in a thin solution of shellac.

Instead of using a pendulum for producing (through an electro-magnet) the marks spacing seconds on the paper, which is the usual device, some other method was found necessary that would admit of greater compactness and portability, for the chronograph was to be used not only on the surface, where the pumping-engines were situated, but it had to be adapted to underground use, and those who are acquainted with the general arrangement of a deep mine pumping compartment, especially on the Comstock, where the air is heavily surcharged with steam from the excessively hot water of the mines, know that the difficulties to be overcome were not slight, and compactness was absolutely necessary, as the whole instrument when

in use, had not only to be protected from the steam and dripping water, but had to be set up in such cramped spaces as could be found available, without any further preparations, and the time for adjusting the instrument as a whole, ready for use, had, in all cases, to be as limited as possible, as the temperature in which I was obliged to take diagrams sometimes reached 110°.

After numerous experiments the use of a chronoscope (or timer), such as is to be had for timing horse races, was made to give satisfactory results. (See Fig. 18.) The method adopted was as follows: A stand or base-plate, upon which the timer was placed, had a brass stanchion suspending a fine platinum wire directly over the second-hand; this wire, when at rest, bore on a piece of platinum inserted in a rubber insulator projecting from the stanchion, each of these wires being connected in the usual manner through the electro-magnet on the chronograph to a two-cell battery. A circuit was always formed except when the hand of the timer, revolving once every second, swings the suspended wire free from its metal bearing at the apex of the triangular notch cut in the rubber guide-piece; as contact was broken every revolution of the second-hand, the armature recorded the same by a side movement of the steel tracer resting on the prepared paper of the drum.

The suspending wire was made adjustable in various directions to suit the second-hand, and, when once adjusted, the whole instrument was covered with a glass case protecting it from moisture, and could be transported and used with rapidity and without further difficulty.

Mr. Briggs states (in his paper above referred to) that Professor Hilgard used a chronoscope for the Navy Ordnance Department, in which the second marks were 30 inches apart. I have found no trouble in speeding the revolving drum of 6″ diameter, until the second marks were 20 inches apart, but for practical use, a length of three to ten inches (depending somewhat on the engine speed) was all that was desired, and by use of a standard steel scale, with the inch divided into hundredths, changes of motion taking place in the $\frac{1}{100}$th part of a second were easily read and recorded without trouble, and the crossing of lines due to the too frequent revolution of the recording drum during one stroke of the engine was avoided. The

use of the small electro-magnet—on the tracer carriage, to raise for an instant the tracing pointer off the drum at any desired point—was found necessary in determining the effects of elasticity in the interruption and variation of motion, where a *long* line of pump-rods was used, and was also found useful in fixing positively the exact point of closing or opening of the steam valves of the engine, independent of all reference to the indicator cards taken.

Two drawings, giving different views of the chronograph as constructed and used, are attached to this article, exhibiting details of construction to complete what otherwise might be considered a defective description of the instrument.

It may not be out of place here to state that the instrument has been successfully applied to several of the different types of large pumping-engines found on the Comstock Lode, such as direct-acting fly-wheel engines, geared pumping-engines, and the "Davy engines;" it has also been used to determine the motion and relative motion of pump-rods, and pumps some 2500 feet below the surface-engine driving the same, and at intermediate points. The results are exceedingly interesting and instructive, and as numerous indicator cards were taken from the engines and pumps simultaneously with the motion diagrams, nearly all conditions of motion and power, during the time under consideration, were definitely determined, and may hereafter form the subject of other papers when time will permit.

Some very important results of the elasticity of long pump-rods are clearly set forth in one case: A rod at a point 1800 feet below the surface showed a positive pause, while the engine driving it was nearly at its point of maximum motion, and pumps attached to the rods may have, and do have, strokes in excess of or less than the *stroke of engine driving the same* and to an *important extent*. Hence, I think, it can be definitely stated that any consideration of motion of pumps, or discharge capacity, driven by a long line of pump-rods based upon the motion or stroke of a surface-engine alone, will in no way be even approximate unless the elasticity and effects of counter-balancing by balance bobs on that elasticity is also considered.

The effects of different degrees of compression upon the engines and motion of the pump-rods in passing the centres have been considered, and the diagrams clearly show the im-

portance of considering it in connection with the strength of the rods and balance bobs.

My latest use of the instrument in conjunction with an engine test has been to determine, if possible, the rate of condensation of steam per second in the steam cylinders of a pumping-engine, where the change of motion due to each fractional part of the stroke was determined. Also, a ten hour experiment trial, to show the economy of compression, as compared with a ten hour trial of the same engine on the succeeding day, where no compression was used (otherwise all conditions being similar), has been made, when changes of velocity of piston were determined by the chronograph. I hope some time to make public the results of these observations for the use and criticism of those interested, after the labor of working them up and tabulating them is completed.

While it is well known that a committee of the British Association applied a chronograph of Morin's type in 1843-4, to the determination of the velocity of piston for a Cornish pump-engine, I believe there was no application of the instrument to the rods below ground, and, from published records at my command, I am led to believe that this is the first application of a chronograph of sensitive construction ever made to pit work and the other purposes so briefly mentioned.

Lettered Reference to Figures 18 *and* 19 *of the Instrument.*

C C—Cast-iron base-plate, covered with sheet-brass, upon which the mechanism is secured.

B—Metal frame containing gearing for driving drum A and escapement-wheel b; motion communicated by means of adjustable weights D.

A A—Light brass drum, accurately balanced, revolving on friction rollers 8, 8, at both ends.

f f—Parallel guide bars upon which the tracing-point h_0 and its carriage travel back and forth, receiving motion in one direction from the engine or other moving parts through the cord P, passing through the bars *f*, and attached to the tracing carriage; the return motion is derived from a coiled spring in the spring drum C.

e e—Small electro-magnets on tracing carriage for raising the tracing-point h_0 off the paper and replacing it at any desired point to be especially observed.

d—Electro-magnets on separate carriage *kk*, adjustable on parallel bars *f*, operating the steel tracing-point *g*, attached to the armature of *d*, for the purpose of recording seconds on the margin of the paper or at other parts of same as required.

i—Chronoscope or watch supported on frame *x*, the second-hand of which swings the light platinum wire J, breaking contact with the insulated wire *k*, thereby breaking circuit with *d* and recording seconds through the tracing-point *g* on the paper.

q—Adjusting screw for the wire J.

a—Steel spring of escapement. This spring is securely clamped in Y, its flexibility being controlled to a certain extent by means of the thumb-screws *o* and *p*.

Discussion.

Professor Thurston: When Mr. Eckart was about to begin his work on this subject, I suggested that he first describe the apparatus he proposed using, and his methods, and finally give us a carefully worked-up series of papers on the result of those methods. He has an instrument that can measure time to the thousandth of a second, which can give us velocities with such precision that we can measure the variation of the piston from the harmonic motion with perfect accuracy. Mr. Eckart has set himself about the preparation of such a series of papers, and this, although perhaps the least important of all, is interesting. He is a very careful worker. In fact, I have not met in the profession a man who seemed better adapted to the application of fine measurements to experimentation on the steam-engine. The paper gives his general idea of the machine, and the drawings will show you very exactly what the instrument is. In the first place, there is a revolving drum. An escapement gives it a perfectly smooth and perfectly uniform motion. It is capable of very exact adjustment. It is so delicate in its operation, that in fitting a piece of smoked paper on the surface of the cylinder, it is necessary at the point where the parts lap, to smooth it down with sand-paper until the thickness through the lap is exactly the same as the thickness of the rest of the sheet. So Mr. Eckart covers this brass cylinder with a sheet of very thin smooth paper, which has been given a coating of soot. That

coating is just thick enough to perceptibly cover the paper. He wraps his paper around and makes a joint where he can, and then smooths down that joint until it is of exactly the same thickness as the rest of the sheet. His cylinder revolves at a suitable uniform rate of speed for the velocity of his engine, and now the problem is to procure upon that revolving cylinder a mark, a curve, that shall represent the motion of the engine with exactness. There is a little carriage, which can be drawn backward and forward on two wires, which form its travelling way, by a cord which is led to the cross-head or some other part of the engine, and it moves back and forth on that pair of rods, with exactly the motion of the piston. That carriage carries a pair of electro-magnets which actuate a little pointer, which is pinned down, and just touches the soot on the paper without touching the paper itself; and as that moves backward and forward, a succession of sparks is passed from the battery, and those sparks prick the paper, remove the soot at the point of contact, or the pointer itself will just touch the soot and scrape it away; sometimes one method is tried and sometimes another. I think Mr. Eckart allows the point to touch; and as this little carriage thus moves backward and forward, that pointer will describe a curve on the paper, which is a perfect record of the velocity of the piston throughout its stroke. Then, in order to get a time movement, he attaches another pair of electro-magnets, which move another pointer of the same kind, but which is stationary at a certain point in the length of the motion. That pointer if left to itself will describe simply a circle. At the end of each period he wishes to measure, connection is formed here with a battery, and that pointer is thrown out of place by the action of these electro-magnets, and that produces a little indentation in the line, and that marks the end of a second, or end of a quarter second, as the case may be. Now divide up that interval, which may be several inches on the cylinder, into as fine parts as you choose, and you so measure your time into as small a fraction of a second as you like. Again, there is a time pointer at one end of the machine, touching the soot on the paper at that point, and a carriage which traverses the bar synchronously with the motion of the engine. Also, there is a time-piece, an ordinary time-keeper's watch, which is set in a little case, and that makes and breaks the circuit. With such an instrument, properly made and adjusted, we have in our

hands a power to make experiments with a steam-engine, and acquire data that never could be obtained before.

Mr. Woodbury: What relation does the length of that cylinder which is covered with paper, bear to the length of the stroke of the pump or engine?

Professor Thurston: I am not certain whether he gives the size. I cannot answer that question. The instrument has been used in the mines of the Comstock Lode. You may judge something from the size of the watch of the size of the instrument. But the instrument has been very carefully made. He sent me some of the curves obtained from pumping-engines, in which, although the engines had a balance-wheel that weighed something like a hundred tons, the effect of a change of compression of one notch, without any other change, is seen in the change of speed in the engine as it brings up on that cushion of steam. It is wonderfully fine work.

Mr. Woodbury: As these meetings are for the interchange of experience, I would make bold to refer to some work of my own upon that same subject.

At the test of the Lowell pumping-engine in 1873, the commission wished to measure the velocity of the fly-wheel at consequent points in each revolution, in order to ascertain the extent and perhaps the cause of its variable motion. I tried a chronograph from the physical laboratory of a scientific school in Boston, but the tremor of the pumping station and the poor quality of the clock-work rotating the drum, vitiated all of the results.

Subsequently, I devised an apparatus, which operated satisfactorily on this and other engines. In previous chronographs, the results have been obtained by recording on a drum moving with a uniform rotary motion, the closing of an electric circuit at the intervals required to be measured, the regular closing of the circuit by clock-work being really a check upon the motion of the revolving drum. For this work, I reversed the relation of the various portions of the chronograph by applying the irregular motion to the pulley carrying the record, which was made on a strip of telegraph paper by a pencil attached to the armature of an electro-magnet, whose circuit was closed at regular intervals.

The apparatus was contained in a box a foot and a half long, a foot deep and about four inches wide, and is shown in Fig. 20.

It consists of a pulley mounted on a shaft, which terminates in a wedge, like a screw-driver, which is held against a slot across the centre at the end of the shaft carrying the fly-wheel; so that the motion of this pulley coincides with that of the fly-wheel. As it revolves, a band of telegraph paper, supplied by a reel, passes around it. A pencil pressed down by a spring and placed directly over the pulley is attached to the armature of an electro-magnet.

The circuit is closed two hundred times a minute by means of a marine clock arranged in the following manner:

A very fine hole was bored in the end of the pallet arbor, and a pin about half an inch long firmly inserted; on this pin a copper wire shaped like an inverted ∩ was attached at its centre of gravity and vibrated in unison with the escapement.

Underneath the ends of this copper wire two drops of mercury connected with the wires in such a manner that when the ∩ was in a vertical position, the points would touch the meniscus of the mercury, and the current passing through the wire from one drop of mercury to the other would close the circuit.

This furnished a means of rapidly closing the circuit by the use of simple and portable apparatus. This arrangement was so accurately balanced that it did not prevent the clock from keeping correct time, as shown by a comparison with a chronometer for several days.

A telegraph key, designed for the purpose, was fastened on the engine in such a manner as to close the circuit when the crank passed over the centre.

When the circuit was open, the pencil would trace a straight line on the paper; when it was closed, either by the clock or the key, the electro-magnet would draw the pencil to one side, thereby producing a sharply defined serration on the paper. By measuring the distances between these serrations, the velocity is determined. Thus, if such a distance measured two inches, and the time intervening between two consecutive closings of the circuit was one two-hundredths of a minute, the velocity of the face of the pulley would be $2 \times 200 = 400$ inches per minute or 0.556 feet per second.

By means of the key recording the position of the crank, the position of the various points whose velocity is thus indicated is thus given for a number of points in each revolution; and the instrument will record many consecutive revolutions, each time

making a series of measurements for different positions of the crank.

These curves represent the velocity of a point on the fly-wheel five feet from the centre, the ordinates showing the velocity in feet per second, and the abscissæ, the position of the crank. At zero the crank is in a vertical position, the crank-pin being over the centre; at 25 the crank-pin is horizontal with the centre; at 50 it is below the centre; at 75 it is horizontal with the centre; and at 100 it is in the same position as at zero.

The following table gives the elements of the curves (see Figs. 21, 22), of two well-known beam-pumping engines, and that of a horizontal stationary engine which gave trouble by its irregular motion. Much of the difficulty could have been remedied by the use of a heavier fly-wheel, as the speed of the engine could not be increased for this special work, and also by using steam at a lower pressure and following a greater portion of the stroke.

Of course, such devices would be only make-shifts to reduce inherent faults in an engine which was manifestly unfit for the work assigned to it.

TABLE SHOWING VELOCITY OF FLY-WHEELS AT POINT 5 FEET FROM CENTRE.

Portion of Revolution.	Lowell Pumping Engine.	Lynn Pumping Engine.		Horizontal Engine.
	Revolutions per minute.			
	13.26	18.61	13.90	19.39
	Velocity in feet per second.			
.00	6.42	9.80	7.13	10.16
.04	6.46	9.82	7.27	10.62
.08	6.54	9.92	7.53	10.84
.12	6.68	10.08	7.72	10.96
.16	6.84	10.14	7.75	10.90
.20	6.96	10.16	7.70	10.72
.24	7.06	10.10	7.53	10.42
.28	7.10	9.96	7.33	10.04
.32	7.06	9.70	7.02	9.58
.36	7.02	9.43	6.60	9.25
.40	6.92	9.23	6.20	9.14
.44	6.82	9.08	5.87	9.27
.48	6.77	9.00	5.73	9.66
.50	6.75	8.97	5.71	9.92
.52	6.77	9.00	5.82	10.17
.56	6.88	9.14	6.20	10.58
.60	7.02	9.30	6.68	10.82
.64	7.13	9.53	7.07	10.85
.68	7.22	9.80	7.40	10.72
.72	7.24	9.97	7.66	10.43
.76	7.24	10.07	7.78	10.00
.80	7.17	10.14	7.85	9.73
.84	7.06	10.12	7.78	9.64
.88	6.94	10.10	7.61	9.68
.92	6.78	10.02	7.34	9.74
.96	6.62	9.90	7.20	9.87
1.00	6.42	9.80	7.13	10.16

This record on the telegraph paper also gives the time of each revolution to .002 of a second.

In the case of the Lowell engine, 11 consecutive revolutions each required the following time:

Number of Revolutions.	Time in seconds.
1,	4.566
2,	4.512
3,	4.579
4,	4.500
5,	4.500
6,	4.555
7,	4.426
8,	4.504
9,	4.534
10,	4.522
11,	4.576

In referring to this matter I make no comparison at all with the delicacy of the apparatus described by Mr. Eckart, but merely brought it to your attention because analogous results have been obtained by a less expensive apparatus which satisfactorily served its purpose.

Added since the Meeting.

In replying to Mr. Woodbury's questions, I will say that the length of drum is twelve inches, and but ten inches of that length was used for the curve traced when the stroke of the pump was ten feet. A much longer drum can be substituted if desired, but that length was found ample and reliable in recording the piston velocity of a pump-engine at eighty feet per minute, and also that of a hoisting engine with piston speed of 1400 feet per minute.

I do not understand from the description of Mr. Woodbury's instrument, and the manner in which he applied it, how he is to get analogous results, for there are no fly-wheels or rotating shafts about a Cornish or Davy Differential Engine, or pumps by which the telegraph paper and pulley he describes could be driven, and I have found from experience that if a reciprocating movement is given by a piston or a pump rod to a drum, or sliding frame, any equal time marks, made either by pencil or spark dots upon the recording paper, merge into a continuous line or become indistinct near the end of stroke, and further, as there can be no movement of the recording paper at the end of stroke there can be no record of the duration of pause, should the pumps or engines make one.

The element of cost, as Mr. Woodbury states, is against the instrument, but the results obtained from its use, however, are certainly very accurate, and leave no part of the piston motion undetermined. W. R. E.

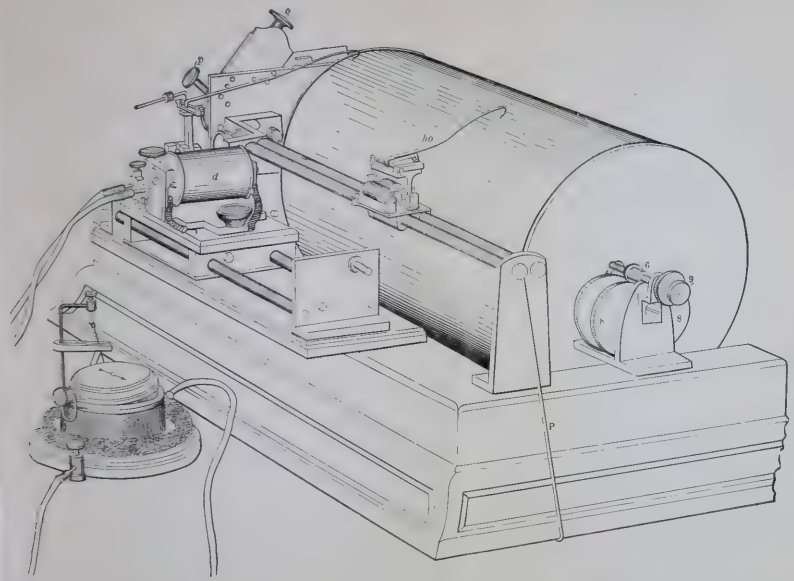

Fig. 18.

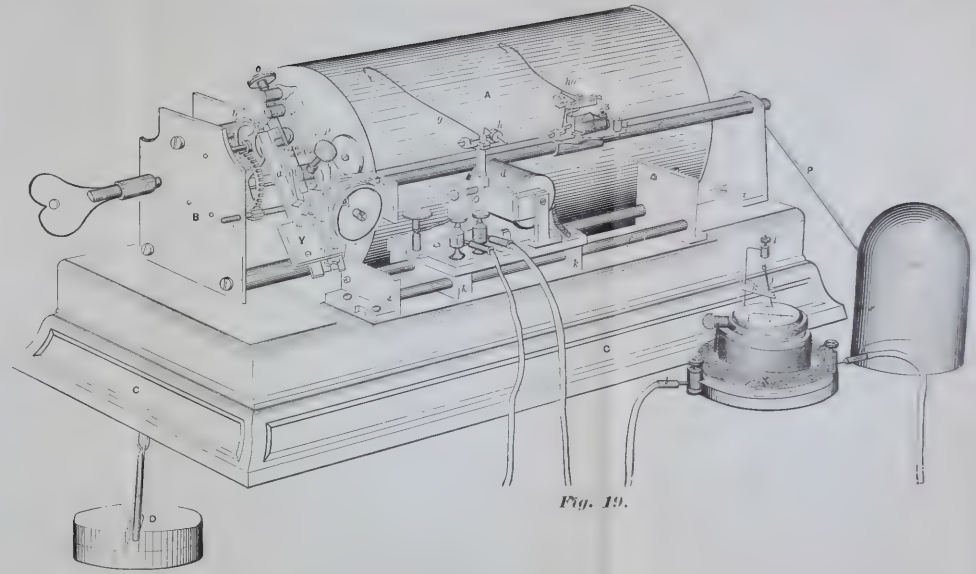

Fig. 19.

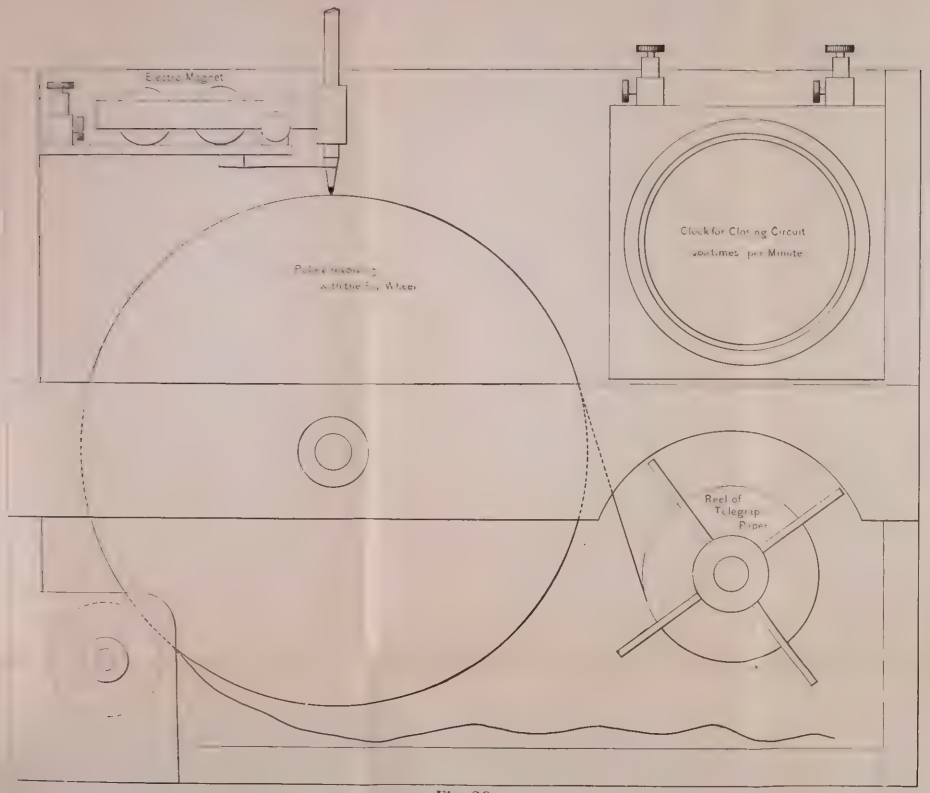

Fig. 20.

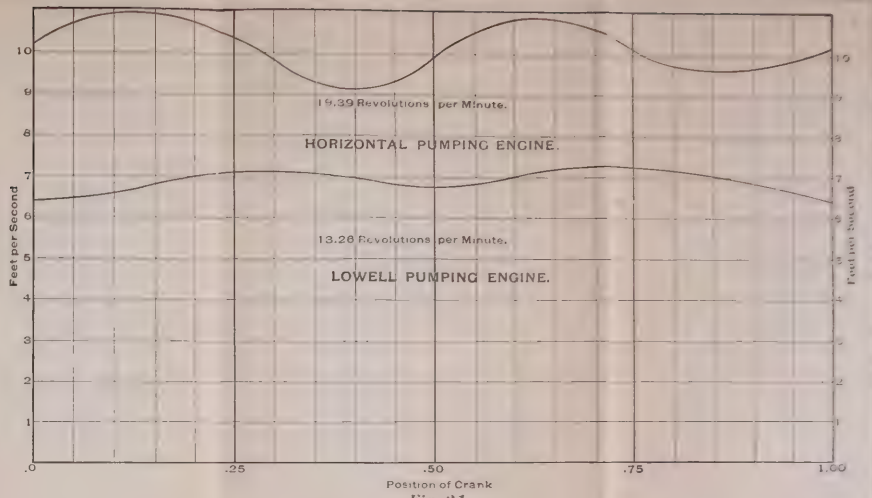

Fig. 21.

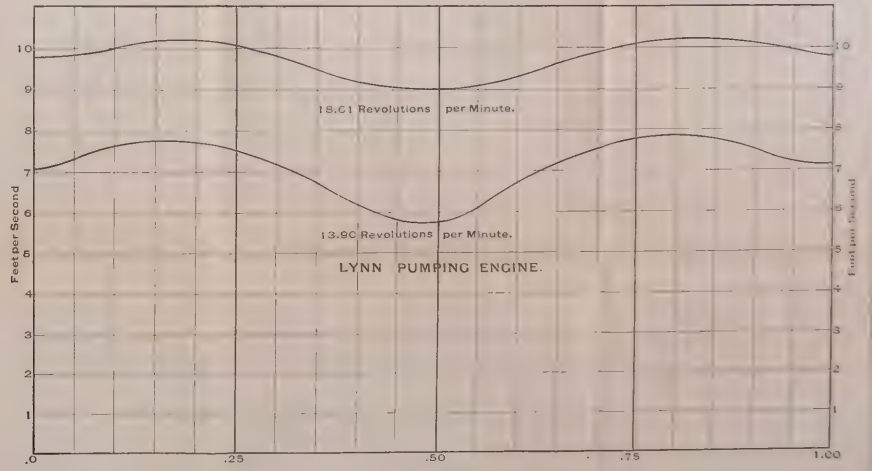

Fig. 22.

LXVII.

BUILT-UP WORK IN ENGINE CONSTRUCTION.

BY

HORACE SEE, PHILADELPHIA, PA.

THIS paper is intended to treat in as general and brief a way as possible of some of the advantages resulting from the use of built-up work in engine construction.

It will be desirable for you, before proceeding farther, to understand what is meant by the term "built-up" as applied to the subject under consideration. We mean a structure formed by the union of several simple members, these members or pieces being such as can be most conveniently, quickly, and economically made to give the necessary strength. Some object to this form of construction from mistaken ideas of economy, others from a false interpretation of beauty, but the largest class from extreme conservatism.

The advantages can be better understood by considering how a few of the forgings and castings, shown in the accompanying illustrations, entering into the construction of a compound marine propeller engine, are made.*

The following extract from a letter in *Engineering* of August 19th, 1881, strikes the keynote of the subject: "The fact will doubtless have its influence for all time coming, when the shafts for gigantic steamers are to be ordered, as it is absolutely impossible to insure that a forging shall be perfectly sound and destitute of flaws if, when it leaves the hammer, it is such an immense and ponderous mass as to weigh fully thirty tons, as did the one fitted into the 'Servia,' being eventually finished, however, at about eighteen tons in weight. All such shafts in future will doubtless be built."

The same argument applies to the solid forked connecting-rod, which requires about 50 per cent. of its weight to be taken off after leaving the hammer, with the attendant risk of not discovering the flaw until near the completion of the work. The impossibility of insuring soundness in forgings which require to have

* See note (*a*) appended.

from forty to fifty per cent. of their weight taken off after leaving the hammer, to bring them to the proper finished shape, should certainly cause the abandonment of a practice with so much uncertainty hanging over it, and lead to the adoption of one where the hammer can fashion each piece to nearly the required shape, where but a small portion of the rough material has to be removed, and where the risks are a great deal less. All of these requirements are met by the built-up system, which has also the additional advantage of furnishing to the forge such shapes as can be more easily made with the fibres of the material running in the proper direction.*

With castings, the evils resulting from crowding too much into one piece are of an analogous character. We will take a bed-plate to illustrate this. Two patterns, each consisting of one fore-and-aft and two athwartship members, have to be made, and the mould for each built up in loam. It is quite likely that the moulding of one will have to follow the other on account of a limited amount of room in the foundry, either on the floor or in the ovens. In the machine-shop the largest planing-machine is called into play, and that, quite possibly, not able to plane more than one piece at a time. Each piece will also have to be set twice.

Here the evil is not so much from the weakness of the structure as from the adoption of a slow and expensive system. This system will doubtless have to give place to the built-up, by making each member of the bed separate, where but one pattern is required for the athwartship and another for the fore-and-aft pieces. This subdivision also allows you to make castings in green sand. All of the athwartship pieces can be planed together at one setting as well as the fore-and-aft one, and on a smaller planer than in the other system.

This subject could be elaborated, but I think enough has been said to call attention to and furnish food for reflection upon a very important part of steam-engine construction.

Discussion.

Mr. Kent: In regard to this paper which has just been read, a gentleman here, who studied steam engineering under Rankine, and who had some experience in the shipyards of the Clyde,

* See note (*b*) appended.

said that marine engineering was going to reach a limit soon in regard to cranks and crank-pins and crank-shafts. The paper before us I think points out one possible line of development, that is built-up pieces instead of solid pieces.

MR. SEE: There is one thing which results from this built-up system worthy of notice. In the construction of the crank-shaft, for instance, under this system, one or more kinds of material can be employed—either iron entirely, or iron in one part and steel in another.

MR. KENT: I suggest two things. Use steel in place of iron, and go as far away as possible from the ordinary hammer, using the hydraulic press. Professor Thurston will probably recollect a sample sent to Hoboken, showing the effect on a small ball of alloy about three-quarters of an inch in diameter, which had been pounded until it had grown about two inches in diameter. I am told by some very good hammermen, that it is possible by hammering a little on the surface of a forging to develop any flaw that exists there into a very large hole.

MR. SEE: I will state here that the crank-shaft of the 'Servia," made to replace the one condemned, was built up and made entirely of steel by Mr. Vickers, the distinguished steel manufacturer of England.

PROFESSOR THURSTON: I do not know precisely what is the phenomenon that occurs in that enlargement of parts under a light hammering. But I know that I have seen large shafts break to pieces under a light hammer. If there is a weak weld anywhere, or a broken weld, a light hammering simply results in the breaking of the shaft to pieces. I have seen shafts built under a light hammer in which you could force a wire along the axis for, I suppose, two or three feet. But I have no doubt, as Mr. Kent has suggested, that ultimately we will come to the use either of very heavy hammers for this class of works or preferably of the hydraulic press. My own impression is that the hydraulic press will be used. But I think that the Whitworth system will likely take the place of that. So that the direction of improvements in construction seems to me the securing of the right kind of metal, which is the right kind of steel. I was talking to a gentleman a few days ago, who was making some designs for pieces of heavy steel. I found that he had such sufficient confidence in a method of hardening to adapt his designs to the use of such a metal, a steel which

could be hardened in masses of eight, nine, and ten inches thickness. I have no idea how such a thing can be done, but I have no doubt that the time will come when a way will be found to do it. I have no question that some kind of steel will be the material we are to use, and that it will be put in shape by some form of hydraulic pressure, if it is done in the plastic state, or more likely by casting in form. My own impression has been for a long time that the Whitworth method, as now adopted by Whitworth himself, will be before very many years the usual method in the construction of these large shafts. The material being found, that method of working being adopted, this system of building up, which has been practiced more or less ever since I can remember, the building up of pieces, will be practiced wherever we have working facilities sufficient; and I see no reason to anticipate that any limit is to be found—that is at any early period—either to the size of parts, or the magnitude of machinery, or the power. I myself have no doubt that we shall build steamers twice as large as the "Great Eastern" without especial difficulty.

Added since the Meeting.

(*a*) There is shown, in Fig. 23, first, a solid crank-shaft as it appears when it leaves the hammer and after it has been finished. Then a built-up shaft when completed, made out of five separate pieces, that is, two shafts, two cranks, and one pin. Second, a solid connecting-rod as it appears when it leaves the hammer and after it has been finished. Then a built-up rod when completed, consisting of the rod proper with a T-head forged on at each end, and two T-headed bolts and nuts let into and secured to opposite sides of cross-head end of rod. And last, a solid bed-plate consisting of two complex and a built-up one of five simple members.

(*b*) A case lately occurred where it was necessary to replace a forked connecting-rod on a 1600 indicated horse-power engine. The condemned rod was of the solid type, and took to forge and finish, working ordinary time, sixty days. It was also the second forging made, the first one being found defective after a great portion of the machine work had been expended upon it. The new rod was built-up. The time taken from the date of order until finished complete with boxes bolted on, working day and night, was fourteen days. This saving of time was undoubtedly due to the simple form of the forgings, with the accompanying advantage of being able to divide the machine work amongst a number of tools, each working at the same time on its special piece. On a solid rod but one tool could work at a time, with the risk of not discovering a flaw until the last was engaged on it.

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LXVIII.

AN ESSAY ON MECHANICS AND THE PROGRESS OF MECHANICAL SCIENCE—1824 *TO* 1882.

BY

FREDERICK FRALEY, LL.D., ONE OF THE ORIGINAL MEMBERS OF THE FRANKLIN INSTITUTE, AND PRESIDENT OF THE AMERICAN PHILOSOPHICAL SOCIETY.

With an Introduction by Coleman Sellers, M.E., Passed Vice-President of the American Society of Mechanical Engineers.

Introductory.

When it was proposed to hold a meeting of the American Society of Mechanical Engineers in the lecture-room of the Franklin Institute in Philadelphia, President Thurston suggested the desirability of a paper on the part played by the Franklin Institute in the progress of the mechanic arts in America, and he so advised the Local Committee. It happens that the present Treasurer of the Franklin Institute was one of those who organized the Society in the year 1824, and he has been not only a member ever since, but he has at almost all times been engaged in the management of the institution. It is natural to turn to one who has taken part in the active work of the Institute for fifty-eight years for information, so it comes that the writer asked his friend, Frederick Fraley, LL.D., to prepare the paper herewith presented. The Franklin Institute of the State of Pennsylvania for the Promotion of the Mechanic Arts, has, through its more than half a century of existence, done much to earn its full title. While mechanic institutes started at the same time have long since passed out of existence, this Institute, founded on the broad basis of uniting all who are to give and obtain instruction, has grown and prospered. Its prosperity, and the work it has done, afford a useful lesson. It has never confined its membership to mechanics only, but while its constitution provides that its Board of Management shall hold a majority of manufacturers, it draws to itself all who are in any way interested in the progress of the Mechanic Arts, and this bringing together of men of varied interests on the common ground of seeking for information, has had the best possible result. Mr. Fraley has repeatedly told the

writer that he owes to the Franklin Institute the greater part of his education, and much of his success in life. In asking for this contribution to the history of a scientific society, it is hoped that the information given may be of use, not only to kindred societies, but even to one that is more limited in its range of membership than is the case with the Franklin Institute.

ESSAY.

FREDERICK FRALEY, LL.D.

I have been a member of the Franklin Institute since its organization in 1824, and this is the only right I have to present this paper for your present session.

When I recall my early remembrance of the mechanic arts in this city in the days of my youth, and compare them with what I see around me now, it is difficult to realize the change or to make any satisfactory comparisons. What was true of the condition of mechanical science in this city at the beginning of the present century was more so of every other part of the United States, and comparatively so, of the continent of Europe and of the island of Great Britain. The active inventive genius of the English and French people in the latter part of the 18th century was beginning to develop the germs of the great machines that have since been perfected, and have, it may almost be said, revolutionized the world. The laws of motion and the application of the mechanical powers had become to some extent known, and chemistry was rising in importance and aiding in carrying on the processes which were to subdue the rude natural materials which were to supply the mechanic with the means for carrying on his labors.

What was needed was the establishment of some kind of school that should bring together intelligent men of different professions and occupations, and by mutual support and study increase the amount of useful knowledge, and divide and distribute it to form new combinations and to make the growing wealth of such acquisitions available for the common good. It was for these ends that the Institute was founded, and its history truly records the growth, advancement and present state of mechanical science in the world. As it was the first really educational mechanics' association in the United States, it has continued to hold its rank as "*primus inter pares.*"

Let us consider for a moment with what we had to deal in its origin. There were a few small and isolated workshops in which mechanical trades were carried on with rude and imperfect tools, and perfection depended more on the strength and skill of the hand of the artisan and on the acuteness of his eye, than on any clear mental perception of what he was doing or that the doing of it could be reduced to anything approaching scientific rules.

I recollect my visits to some of the well-known workshops of those days, and have seen Patrick Lyon striking vigorous blows on his anvil, Oliver Evans in his foundry, Jacob Perkins in his fire-engine manufactory, and the Messrs. Sellers in their then wonder-working wire works, turning out the marvellous hand and machine cards. It was indeed a great privilege to be permitted to visit those establishments, for they were the pride of their proprietors, and were not to be entered by all with impunity.

But with the establishment of the Institute came a new phase of these things. There had been for some years a sort of mechanics' club, which zealously guarded additions to its membership, and was so much attached to ancient mysteries, that it mercilessly blackballed all who attempted entrance by the shibboleth of modern ideas.

So it happened that Samuel V. Merrick was excluded from this venerable, close guild, and he resolved to form an institution on a more liberal basis and with broader views, and he joined to himself a few congenial spirits, who went manfully to work and called a public meeting of Philadelphia citizens, which was largely attended, and which enthusiastically adopted the plans of the founders, and gave us the great institution in whose Hall you are holding your present meeting.

True it is that Benjamin Franklin founded in Philadelphia, in the year 1743, the American Philosophical Society for the promotion of useful knowledge, but mechanical knowledge in that day did not hold the place it now does.

While Franklin followed a mechanical trade and did much handicraft work to make his printing attractive and profitable, he soared to higher heights and became philosopher, statesman and political economist, by which he earned his great and glorious name.

Philadelphia has always been distinguished for the beauty and excellence of its mechanical productions.

In the earlier part of the present century she was the point of attraction for purchasers from all parts of the United States.

It was therefore eminently fitting that a great mechanics' educational institution should be established in that city.

The plans for it were comprehensive, and struck down to the very roots of what was needed.

It took hold of the grown and skilful men of all trades, blended them with merchants, lawyers and scientists, put them all in personal and friendly contact for the communication and diffusion of all they knew, and then made provision for the education of the young in a high school, to be characterized by the teaching of what would be useful in practical life.

It established the first regular school in the United States for instruction in mechanical drawing, and has kept it in successful operation for more than fifty years. In the first year of its existence it had courses of lectures on mechanics, chemistry, architecture, natural philosophy, and volunteer lectures on particular arts and trades. These lectures were attended by numerous classes, and made a great impression on the public, which increased the power and promoted the success of the Institute. This success gave it courage to hold an exhibition of American manufactures, the first held in the United States; and the specimens of American skill then presented were numerous, well made, and indicated a good basis on which future progress and perfection could be built up. Such exhibitions have been continued at convenient intervals, and have marked the march onward of mechanical skill. By the division of the leading members into standing committees on all the principal objects of the Institute, and by the regular meetings, the whole machinery of instruction was put in motion, and the results were soon apparent. It gathered a valuable library, and cabinets of models, minerals, and manufactured products, and thus soon became an Institute of Technology of the first rank, and that rank it continues to maintain at this day. It seems to be like the fable of the eagle continually renewing its youth, and as the old veterans have fallen from the ranks, the young and vigorous have filled up vacant places with enlarged knowledge and fired with the same confidence and hope.

Another aid given by the Institute to the development of mechanical science is found in its Journal. This publication has been continued monthly for more than half a century. It

contains a full *résumé* of American patents up to the period when the Patent Office commenced the publication of its reports. It contains, besides, many original essays and copious republications of articles on mechanics from foreign journals. By exchanges, it has largely contributed to build up the library, which has now a large store of wealth and technological knowledge.

In the way of original research the Institute can point with pride to its investigations of the value of water as a motive power; of the causes of explosion of steam boilers, of the strength of materials, of dynamo-electric machines, and to its examinations and reports upon many hundreds of new inventions.

These have brought into permanent notice many of the active members, who unselfishly devoted themselves to the elucidation and dissemination of the great truths which adorn the fields in which they labored. To name them all would be difficult indeed, for their number is not small. Prominent among them, however, are Samuel V. Merrick, William H. Keating, Robert M. Patterson, Matthias W. Baldwin, Rufus Tyler, Benjamin Reeves, Isaiah Lukens, Franklin Peale, Asa Whitney, John C. Cresson, William Sellers, Joseph Saxton. One of the early chiefs was Alexander Dallas Bache, who closed his life of devotion to science as Superintendent of the United States Coast Survey, a work which gave full play to the highest forms of accurate and useful applications of mathematical and mechanical knowledge.

In this connection, also, I must strive to pay just tribute to the merits and zeal of its professors, among whom we find in its early days, R. M. Patterson, William H. Keating, William Strickland, Franklin Bache, John K. Mitchell, Walter R. Johnson, John C. Cresson, James B. Rogers, and John F. Frazer. Their successors are numerous and worthy, and they in the present days are upholding the honor and sustaining the reputation of this mother of mechanical institutes of our country. As she was the first of these really educational institutions, the model which she presented has been closely followed, and the benefits which she gave to the mechanics of Philadelphia are now largely shared by the craftsmen in all parts of our widely extended territories, by the labors which such kindred institutions have fully and freely bestowed.

My object in the preparation of this paper was to attempt to show by the history of the Institute, some illustration of the progress of mechanical science for the last sixty years, and to show by the gleanings I have made from this vast field, amid the active labors of a different line of life, the impressions made upon my mind by the truly marvellous triumphs of mechanical skill, which have claimed my admiration and remembrance. If I shall add an hour of pleasure to your meeting I shall be amply repaid for its preparation.

I cannot close it, however, without attempting to bring before you, in contrast, what I saw of machinery and its progress in my youth, and what I see now. I shall refer first to the supply of water to the city of Philadelphia.

Then she was just emerging from the use of wells and hand-pumps, and the rude steam engines placed near the Schuylkill River at Chestnut Street and at the base of the marble building in the Centre Square at Market and Broad Streets; and the modest basin eighty feet at its summit, and sixty feet in diameter, were the wonder and boast of the citizens. The pipes for the distribution of the water were wooden logs bored by hand, and it was not until after the establishment of the Institute that iron pipes were cast in this country. A few had been imported from England, and this fact became a political war-cry, and nearly revolutionized the city government. About the year 1822 the water-works were established at Fairmount, a transfer of the steam-power having previously been made to that point, a large Boulton & Watt engine having taken the place of the original engines. The Boulton & Watt engine was a beautiful piece of work, and marked a well-defined phase in mechanical engineering. For a short time by its side worked a high-pressure engine of great simplicity and with few parts, invented and constructed by Oliver Evans, the great American mechanic, who is probably the inventor of the use of steam under high pressure, and who deserves a high place in the pantheon of inventors. Recollect that then no other large city in the United States was supplied with water by machinery, and that the representatives of city corporations came to study and imitate our example. Now every large city boasts of its water-supply arrangements, and the steam and water powers exhibit the perfection which study and experience give. Compare the locomotive engine of the present day with the embryo of

Oliver Evans; or the machine of Blenkinsop, or the English machines of Stephenson, or the first one of Baldwin, with those which are now daily turned out of the hundreds of the great shops of the world, and notably those of our own country, and you will again realize the progress of your special science.

Look at the manifestations of the same progress from the rude spinning jennies and mules of Arkwright and Crompton, to the contents of a modern cotton or woollen mill, and marvel at the mechanical fingers which spin and weave the massive sail-cloth or carpet, and the gossamers which clothe the queens of kingdoms and of fashion.

Look at the machines and tools of precision, and see how they have contributed to bring about so much perfection.

In this connection, also, the introduction of standard sizes and uniformity in the several parts of machines have tended to great economy and practical usefulness.

How much has been gained by the adoption of the United States standard for screw threads, for which we are indebted in a large degree to the ingenuity and experience of Mr. William Sellers. The stand taken by the Institute to prevent a forced adoption of the French metric system has been of great use in guarding us from a violent and unnecessary revolution in the weights and measures of our country. These are so identified with all our measurements and the welfare and protection of society and property, that to disturb them seems to me to be as criminal as the burning of the great library at Alexandria.

Upon such a survey of the progress of mechanical science as it has fallen under my observation and study, I feel that the men of this century have well performed their duty, but they must keep their hands to the plough and not be content with what has been accomplished. They must cherish the spirit of brotherhood, be ready and willing to communicate and spread all useful knowledge. They must aid in keeping up the great educational institutions of the country, especially in their scientific and technical departments, and so give to the present and coming generations the advantages and accumulations of all the wealth of knowledge which has been obtained by the labors of genius and perseverance, and provide more abundantly for their increase.

LXIX.

AVERAGING MACHINES.

BY

W. S. AUCHINCLOSS, PHILADELPHIA, PA.

THE averaging machine is a device for determining the centre of gravity of a system of representative weights located at any desired distances from each other. These weights can represent dollars, tons, pounds, or merchandise, and the distances by which they are separated can represent the intervals of time between which purchases were made or the distances by which specific loads are separated. In the case of time intervals, the location of the common centre of gravity of the representative weights will determine the average time of purchase, while in the case of distance intervals the common centre of gravity will be located with regard to a common starting-point, or zero.

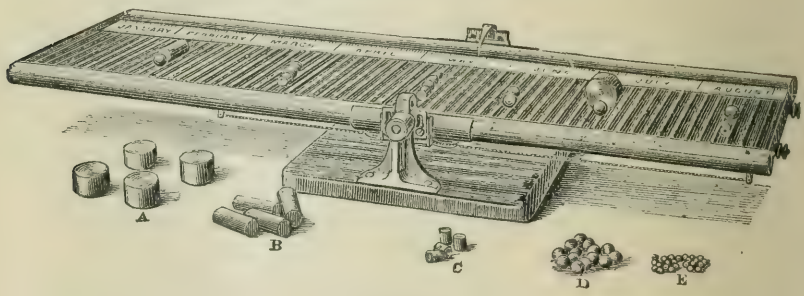


FIG. 24.

The first requisite of the problem is that, no matter what the position of the unloaded platform, with reference to its points of support, its equilibrium must be perfect. This is easily secured by supporting it on a saddle C, in which it freely slides, and equalizing the weight of the platform by counterweights F F^1, in hollow side-tubes. As the platform A is advanced in the direction No. 1, the counterweights F F^1 move with precisely the same speed in the opposite direction, and thus maintain the equilibrium. This isochronous action of the counterweights is secured by attaching their extremities to the platform A, through the medium of chains passing around four pulleys on the saddle C.

By means of this device the influence of the weight of the platform is entirely eliminated from the problem, which is reduced to that of simply determining the centre of gravity of a system of representative weights.

The weights, for convenience, are made of sizes to represent units, tens, hundreds, thousands, etc. The platform A has a suitable number of equidistant grooves, and the accompanying paper-scales are divided in harmony with the grooves, for the varying problems to be solved by the machine.

In Commercial Transactions involving time problems, the machine will readily solve one hundred accounts per hour.

In Civil Engineering it gives the average haul of excavations and embankments with great rapidity and unfailing accuracy.

In Mechanical Engineering the machine may be used for deter-

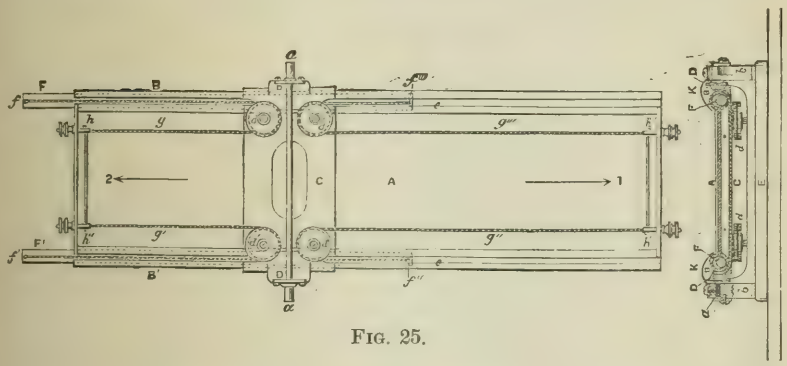


FIG. 25.

mining the location of the centre of gravity of engine, boilers, coals, cargo, etc., before placing same on a steamer; also for determining diameters of pulleys and speeds of shafting.

In Ship-building it will determine the centre of buoyancy for various water-lines; also location of centre of gravity of hull.

In Mercantile Exchanges it will determine the average price of any number of "futures."

The machine likewise solves all examples of arithmetical proportion.

Another form of this same device is shown in the cut, p. 222, which represents the endless chain method. This machine secures greater rapidity of action, and will solve 140 accounts per hour.

After the completion of each problem the endless chain is drawn along its platform and the weights drop upon an inclined

surface, along which they roll to a bar in front of the machine. This bar acts as a screen, and separates the larger from the

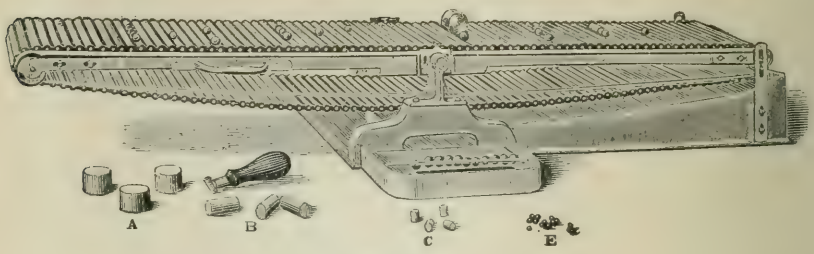


FIG. 26.

smaller weights, after which they are in readiness for the next problem.

Such a machine will work about six times as fast as an expert accountant, and with greater certainty as to the results attained.

DISCUSSION.

PROFESSOR THURSTON: This method has proved an exceedingly useful one in determining centres of gravity in naval architecture. One of the most experienced naval architects I have known in this country has used such a method for the last forty years, and he has built a tank of sufficient length, and in this long tank he places a model of the craft he proposes to build. Then he has a set of weights precisely as here, which represent one ton, ten tons, etc., and he places these upon his model just where he proposes to put engines, boiler, stores, cable, locker, etc., and he determines on the centre of gravity. This gentleman has been adopting that method, which is ruder than this, for a long time, and in preference to all calculations.

Added since the Meeting.

It will be observed that, although the naval architect referred to, secures a satisfactory location of the engines, boilers, stores, cables, locker, etc., his empirical method does *not*, in any sense of the term, locate or determine the common centre of gravity of the bodies, so that the centre becomes a known and definite point.

The averaging machine, however, *will* determine its location with *absolute* precision.

W. S. A.

LXX.

EXPANSION OF STEAM AND WATER WITHOUT TRANSFER OF HEAT.

BY

A. FABER DU FAUR, NEW YORK CITY.

For adiabatic expansion of steam and water the formula of Clausius (as given by Zeuner, in his *Waermetheorie* of 1860, page 114) is as follows:

$$\frac{m_2 r_2}{T_2} = \frac{m_1 r_1}{T_1} + Mc \text{ log. nat. } \frac{T_1}{T_2}. \quad \text{(I)}$$

where—

T_1 and T_2 = absolute temperatures at the beginning and end of expansion.

m_1 and m_2 = weight of steam at the beginning and end of expansion.

r_1 and r_2 = heat of evaporation at and from the temperature T_1 and T_2.

M = aggregate weight of steam and water.

c = specific heat of water.

For $M = 1$, that is, for the unit of weight of mixed steam and water we get

$$m_2 = m_1 \frac{r_1 T_2}{T_1 r_2} + \frac{T_2}{r_2} c \text{ log. nat.} \frac{T_1}{T_2}. \quad \text{(II)}$$

This is also the equation given in Rankine's *Steam-Engine*, London, 1859, page 385, formula (5), using units of heat in place of foot-pounds, J, as stated on page 383, being the dynamical value of the specific heat of water.

The equation (1) is derived from the differential equation:

$$Mc \frac{dT}{T} + d\left(\frac{mr}{T}\right) = 0.$$

The value of c is not constant. Zeuner, page 98, formula (108), and page 88, gives:

$$c = 1.1 - \frac{30.456}{T} \text{ for Centigrade scale.}$$

By substituting this value into the differential equation, and taking the integral between T_1 and T_2, formula (II) becomes for Centigrade scale:

$$m_2 = \frac{T_2}{r_2}\left\{1.1 \log. \text{nat.} \frac{T_1}{T_2} - 30.456\left(\frac{1}{T_2} - \frac{1}{T_1}\right)\right\} + m_1 \frac{r_1 T_2}{r_2 T_1}. \quad \text{(III)}$$

$$m_2 = A + m_1 B. \quad \text{(IV)}$$

where $$A = \frac{T_2}{r_2}\left\{1.1 \log. \text{nat.} \frac{T_1}{T_2} - 30.456\left(\frac{1}{T_2} - \frac{1}{T_1}\right)\right\}$$

and $B = \frac{r_1 T_2}{r_2 T_1}$.

From equation (III) the values of m_2 in the annexed table and diagram of curves have been calculated. The upper curve of the diagram beginning at $T_1 = 473$, and $m_1 = 1$, and ending at $T_2 = 293$, and $m_2 = 0.726588$, represents the expansion of originally dry steam between 473° and 293°; the lower curve, beginning with $T_1 = 473$ and $m_1 = 0$, represents the expansion of water between 473° and 293°. From equations (III) and (IV) it follows that by dividing the vertical distances between the two curves into equal parts, and connecting the corresponding points of division, new curves are obtained which are equally correct; it also follows that the divisions may be continued above the upper curve up to 1 and beneath the lower curve to 0, as in the diagram.

By the use of steam tables the pressure and volume of the steam at the various temperatures is readily obtained, also the heat contained in the unit of weight of steam, so that the heat contained in the mixture of steam and water, indicated by the curves, is easily calculated.

From the values of m_1 and m_2 in the annexed table, I have calculated the exponent or index i in the formula, $\frac{v_2}{v} = \left(\frac{p_1}{p_2}\right)^i$ as follows:

$m =$	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.0
Between 473 and 293.	1.120	1.112	1.103	1.093	1.081	1.066	1.046	1.018	0.976	0.904	0.681
Between 473 and 273.	1.138	1.128	1.102	1.096	1.078	1.053	1.024	0.975	0.912	0.798	0.485

Theoretically the annexed curves show the final conditions of mixed steam and water acting against a piston and expanding between any two temperatures, no matter what the intermediate stages may be, provided that whatever heat the steam may have imparted to its surroundings during part of its action, shall have been restored at the end.

Practically the operation of steam is as follows: The initial condition of steam being represented by A in the annexed diagram (Fig. 27), and the theoretical changes of its condition during expansion by the curve $A\ B$, the cool surface of the cylinder will, during admission, change the initial condition by condensation to A_1, at the same time raising the temperature of the metal; the heat thus lost will be partly restored during expansion, so that the condition of the expanding steam will not be represented by the curve $A_1\ B_1$, but by a curve terminating above it.

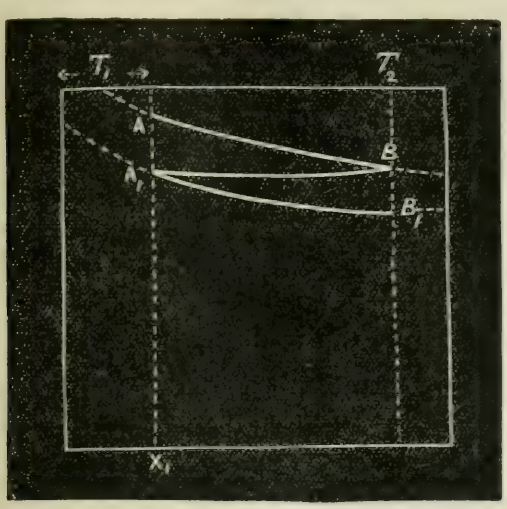


FIG. 27.

If all the heat were restored, then B would represent the final condition of steam, and the energy exerted would be the same as the one calculated from the theoretical curve $A\ B$, although the change of its condition is represented by $A\ A_1\ B$, or by any other line connecting the points A and B.

The total energy exerted by 1 pound of water and steam, during admission and expansion, is then computed as follows:

Heat supplied $= c + m_1 r_1$

Heat rejected . . . . . $= c_1 + m_2 \left(r_2 - \frac{p_2 u_2}{J} \right)$

Heat transformed into energy $= c - c_1 + m_1 r_1 - m_2 \left(r_2 - \frac{p_2 u_2}{J} \right)$

Where:

P_2 = pressure corresponding to final temperature T_2.

u_2 = volume corresponding to final temperature T_2.

J = mechanical equivalent of heat.

c and c_1 = heat units in one pound of water.

It is seen that even if no heat be lost through the action of the surfaces of the cylinders, the alternate rise and fall of temperature of the surfaces will change the curve of expansion so that the calculated index will not apply even to adiabatic action, that is to say, to such action in the steam cylinder, where the total heat absorbed by the surfaces during admission, is restored without loss during expansion.

Practically, however, we have no absolute adiabatic action, part of the heat being carried off mainly by the re-evaporation of water on the exhaust side, that is to say, the cylinder and piston will give up heat to the exhaust, which heat is not restored, but is discharged with the exhaust, and is additional to the rejected heat as theoretically determined. The quantity of heat thus lost must be deducted from the heat theoretically transformed into energy, to get the actual energy exerted.

The quantity of heat wasted with the exhaust, in addition to the rejected heat as theoretically determined, or as shown by the condition of mixed steam and water before the opening of the exhaust port, depends on various conditions, such as the surface of the metal exposed to the steam, the range of temperature, the time of one alternation, or the time required for one stroke ; probably also, to a great extent, the difference between the final temperature of expansion and that due to the back pressure.

We have a great array of special curves proving very little without complete, definite, and reliable data. Owing to the alternate receiving and emitting of heat by the surfaces of the cylinder, the adiabatic curve may take various shapes, but these shapes must be obtained by carefully prepared experiments, and not founded on assumptions or doubtful experience.

We have, also, experiments as to the condensation of steam during expansion, but so far they have not enabled us to calculate what is wanted, namely :

(1st.) The amount of heat transmitted to the exhaust per square foot of metal surface for various conditions.

(2d.) The heat lost per square foot by radiation or conduction.

(3d.) The heat transmitted per square foot by a steam jacket.

A series of experiments especially made for determining these

quantities, and such experiments alone, would enable us to determine the actual rejected heat, and the total energy exerted by steam under all circumstances. Theory shows us what is possible without loss; practical experiment must demonstrate what the loss is, and how it varies under different circumstances.

It surely is much easier, more logical, and more correct to arrive at a positive and conscientious result by adopting what theory dictates, and deducting the actual loss determined by careful experiment, than by attempting to bring crude experimental facts or vague and disconnected experience into a general though questionable rule, without regard to the theoretically possible.

Expansion of Steam and Water without Transfer of Heat.

Absolute Temp. Centig.	473°	453°	433°	413°	393°	373°	353°	333°	313°	293°
Pressure in Atmospheres.	15.38	9.929	6.120	3.576	1.962	1.	0.466	0.196	0.072	0.023
Weight of water per unit of mixed water and steam.	0.0	0.042207	0.080462	0.113731	0.143568	0.169740	0.192420	0.211750	0.227858	0.240818
	0.1	0.135075	0.166680	0.193692	0.217576	0.238128	0.255475	0.269741	0.281022	0.289395
	0.2	0.227943	0.252898	0.273654	0.291585	0.306516	0.318530	0.327731	0.334186	0.337972
	0.3	0.320811	0.339116	0.353615	0.365593	0.374904	0.381585	0.385721	0.387350	0.386549
	0.4	0.413679	0.425334	0.433577	0.439601	0.443292	0.444640	0.443712	0.440514	0.435126
	0.5	0.506547	0.511552	0.513538	0.513609	0.512680	0.507695	0.501703	0.493678	0.483703
	0.6	0.599415	0.597770	0.593499	0.587618	0.581068	0.570750	0.559693	0.546842	0.532280
	0.7	0.692283	0.683988	0.673461	0.661626	0.648456	0.633805	0.617683	0.600006	0.580857
	0.8	0.785151	0.770206	0.753422	0.735634	0.716844	0.696860	0.675674	0.653170	0.629434
	0.9	0.878019	0.856424	0.833384	0.809643	0.785232	0.759915	0.733664	0.706334	0.678011
	1.0	0.970887	0.942642	0.913450	0.883651	0.853620	0.822970	0.791655	0.759498	0.726588
Pressure lbs. per sq. inch.	225.8	145.8	89.7	52.5	28.8	14.7	6.86	2.09	1.06	0.33
Temperature Fahrenheit. (Ordinary Scale.)	392°	356°	320°	284°	248°	212°	176°	140°	104°	68°

Discussion.

Mr. Wolff: In presenting Mr. Du Faur's paper I feel that I have not been able to do it justice, from having just received it and that it is full of mathematics; but at the same time I have been so impressed with the work that Mr. Du Faur has accomplished that I have taken great pleasure in making the subject as clear as I could. Mr. Du Faur has taken the formulæ of Clausius and Rankine for the expansion of steam and water in a cylinder without transfer of heat, has made substitutions in these formulæ for different amounts of initial water and steam in the steam entering the cylinder, and has calculated the condensation for different ranges of expansion. He has thus determined the amount of condensation which takes place in a non-conducting cylinder, owing to the expansion of the steam alone, not owing to any transfer of heat from the steam to the cylinder and its return to the steam, considering the metal of the cylinder entirely as a non-conducting material. I think we all recognize the value of work of this kind. Mr. Du Faur has presented his results both in table and graphically, as you may perceive. We all know that there is a great amount of condensation taking place in a cylinder owing to the expansion of steam alone without transfer of heat, but without tables of this kind or graphical illustrations we are not apt to fully realize the exact amount. I therefore consider it the chief value of the work which Mr. Du Faur has accomplished, that we shall be able in any experiments that may be made in the future, to know at a glance how much condensation is owing to the work done in expanding the steam itself, for internal energy, and how much on the other hand is owing to conduction, radiation, and re-evaporation.

If I may be permitted to add a word to Mr. Du Faur's paper, I would like to say that I think we all recognize at the present time the necessity of determining the amount of condensation of steam in cylinders by experiment, and if I was not aware that such a number of committees had been appointed this evening to look into various matters, I, for one, should call upon our President to nominate a committee for this purpose. I think there is no work to which we could devote our energies with more satisfaction, that there is no work that we can do in the engineering profession to-day which is more seriously demanded

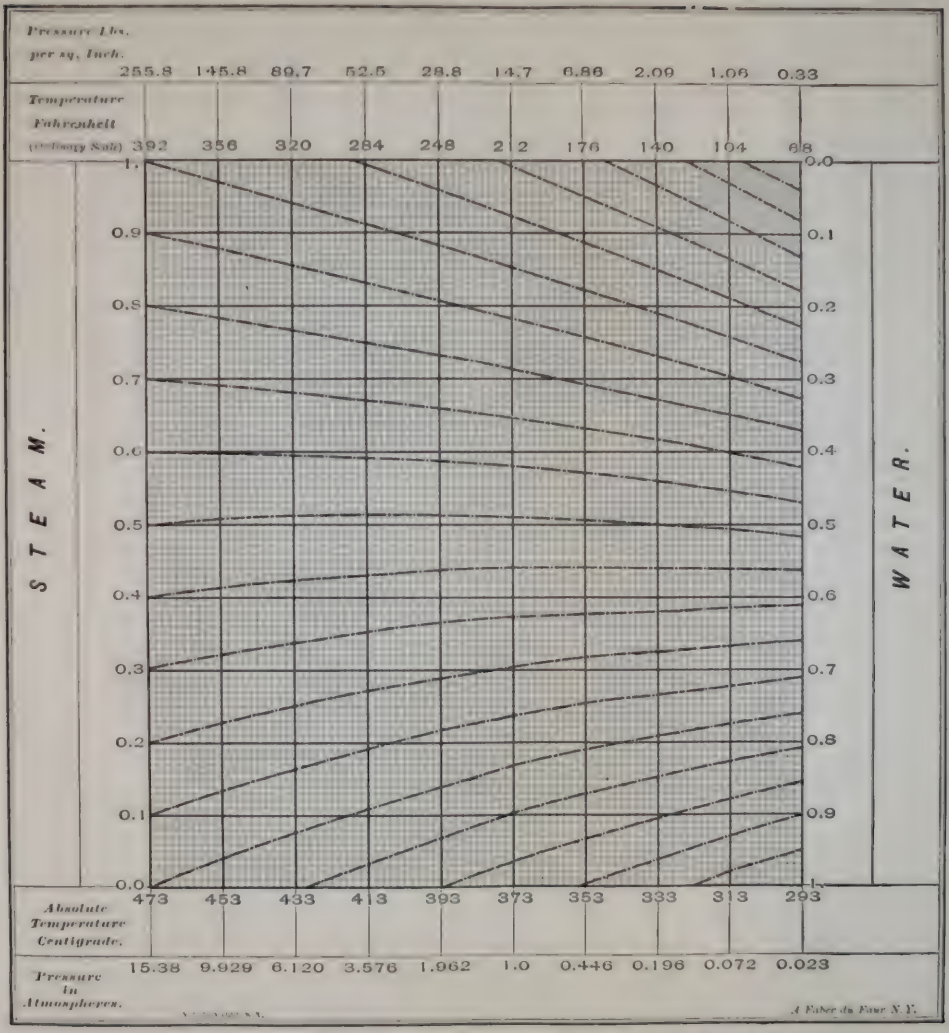
or which would gain for us a greater national reputation. To-day, the little experimental work that is being done in this direction is being done abroad by Hirn, Hallauer, and their collaborators; but until now their results have not been such as to produce definite rules. It might be said that Mr. Isherwood made experiments in this direction. Mr. Isherwood has made experiments which were very cautiously prepared and recorded, as any one who has carefully read his report will see. If any fault can be found with the experiments, it is that he did not determine the condition of the steam as it left the boiler. The mistake that Mr. Isherwood, however, apparently committed, was that the deductions which he made for a particular series of experiments, while correct for those experiments were made more general in their application than was warranted. On engines where the piston speed was not above 300 in any case, usually between 200 and 300, and where the revolutions were very low indeed, a great amount of condensation was found, and this he apparently concluded would be the amount of condensation in all engines. Now, in the *Journal of the Franklin Institute*, for February, 1879, Mr. Isherwood, in speaking of the performance of the engine of the "Mary Powell," which he calls a typical paddle-wheel engine, mentions that no condensation occurred in the cylinder; that evidently the steam consumption with the ratio of expansion used showed that there could be no condensation; hence we have on the one hand Mr. Isherwood a number of years ago making careful experiments where a great amount of condensation was shown, and in 1879, on the other hand, he records the case of a similar engine with no condensation at all. These latter experiments were, however, not made by Mr. Isherwood himself.

I have also looked carefully into the experiments of Mr. Hirn, and find that Mr. Hirn himself has come to no conclusion at all relative to the condensation of steam in cylinders at different ratios of expansion, but states that Mr. Hallauer, his co-worker, will present these results. Mr. Hallauer's paper has been published, and there again we have no definite results obtained. However, the work which they are doing there in France appears to be of the most careful character, is in the right direction, and ought ultimately to produce the desired correct results. Meanwhile, we have to a great extent to rely for knowledge in respect to condensation of steam in cylinders upon such general

information as experience will give us; but I think the information which experience gives us is in many ways very unsatisfactory, and therefore I heartily favor all that Mr. Du Faur says: that specially arranged experiments for this purpose, as to the effect of different conditions of speed, time of exposure, etc., which evidently enter into the practical question of condensation, should be carefully considered. It is only because the other committees have been appointed, and I recognize that the society has its hands full, that I do not now make a motion to that effect.

Professor Thurston: This paper interests me very much, but I do not yet realize all that it contains. I should have to read the paper carefully to see what is there. It interests me to see how many minds are working in one direction, and how many people are recognizing the importance of this subject. We are absolutely at sea with regard to this whole matter. Perhaps I should hardly say that. We are so much at sea that we have no data, and we are uncertain as to our exact course. Even in the theoretical treatment we are a good deal at sea. The exponents that we use in the treatment of these assumed hyperbolic curves are not simply of uncertain magnitude, but it is certain that they do not represent exactly what they are intended to represent. I suppose that all engineers rely upon Zeuner's expression of the value of an exponent. But in looking over his works, you will find that it only approximates the mean value in a case where the value is constantly changing; a mean value as near as he can get it for a certain set of conditions. Those sets of conditions are rarely the same. And then again, assuming that the Zeuner exponent is nearly accurate for every-day work, you will find then that the conditions you meet in experimental work are very different from those assumed in our theoretical treatment, and that the exponent becomes something entirely different from that. I never yet found an indicator card in which the exponent was that given either by Rankine or Zeuner, or anybody else, so far as I know, who has treated that subject. All the indicator cards I have examined have given exponents, either substantially unity, within perhaps one-hundredth of unity, or considerably lower, while all of the exponents given by Zeuner's formula, if we take it within the range of ordinary practice, considerably exceed unity. Then again, after we have got a value for this exponent that suits the expansion curve, if we use that for a determination of the amount of heat likely to be consumed, we

find that we are entirely adrift when we compare that for results. When we go to experimenting to determine what the waste is, we find the experiment does not tell us. In the paper I presented yesterday morning, you will find I took approximate results, and in some cases I could not get any definite results at all, and the best I could get, were those Mr. Wolff has spoken of,—those of Isherwood on the condensing unjacketed engine. Isherwood, in the second volume of his "Researches," presents what seems to me about the average figures for the working of such engines. But on comparing his figures with his work, you will find that the condensation given there, is not the condensation that actually exists, but only an approximation, which he obtains by assuming that his measurement covers all condensation. So that in the best curve of efficiency that I could produce, I still could not reach the point that I wished to gain. I produced a curve which represents Isherwood's figures, but it does not represent actual facts. It is, I presume, fairly approximate, but it is not satisfactory; so that we stand to-day absolutely, so far as I know, without any one complete series of experiments of the kind we want. It is for that reason that the results given in my paper must be taken as entirely provisional, and the best I can hope to do there is to point out a method to be of use when we get such a result. The thing an engineer wants is just this class of experiments. The results must be properly collated, and the exact meaning of those results determined, the probable value of observed quantity ascertained, and probably we should find it even advisable to go into the domain of the astronomer, and determine errors by some of his methods, and after a large amount of work has been done, we can get something that will be of some real service to us. I presume no engineer that understands the matter at all would be at all satisfied with the result on any one class of engines so far as is known to-day. The presentation of a paper of this character, as I say, indicates that engineers are beginning to appreciate these facts, and when this is done for every class of engine running under every set of conditions, we can determine the exact behavior of steam, for every ratio of expansion that can be adopted in such engines, and we then will have a set of figures, a collection of facts, on which we can probably base a treatment that will be satisfactory, and till then we shall be to a very considerable extent in the dark. So far as I have been able to



Expansion of Steam and Water Without Transfer of Heat
Curves Showing Relative Proportions of Steam and Water.

Fig. 28.

ascertain, there is not in existence to-day a set of experiments that are of any very great value. There is no one complete set of experiments on any one of the class of steam-engines to-day in common use, and there are no experiments at all, of the kind we want, on the kind of engines we are most interested in; those that our colleagues are building at the south end of the town, those that you will find built by Worthington, or any of the builders of the class of pumping-engines that are coming into use constantly. We know next to nothing about the behavior of steam in the locomotive cylinders; and I want to emphasize my own views on this subject, so that I cannot by any possibility be misunderstood. I want to be understood as being thoroughly desirous of seeing this kind of work done, and do not want to be understood as being in the slightest degree inclined to prejudge or anticipate results.

Mr. Wolff: I think that the experience which we have as to condensation will enable us to settle some very important problems satisfactorily in practice; but, of course, what we are after are exact data. And I am glad to see that you take the same view as Mr. Faber Du Faur.

LXXI.

DESCRIPTION OF THE EDISON STEAM DYNAMO.

BY

T. A. EDISON, PH.D., NEW YORK CITY,

AND

CHARLES T. PORTER, PHILADELPHIA, PA.

The central Edison station of the first district in New York city will, when fully equipped, be supplied with twelve dynamos, each of which is nominally rated as a 1200-light machine, at 16 candle-power incandescence, but is capable of supplying 1400 lights of this power continuously, and with high economy, without heating the armature, or burning or injuring the commutator or brushes. This increased capacity is due to improvements in the lamp itself.

The armature of each dynamo is driven by a Porter-Allen engine, of $11\frac{3}{16}''$ diameter of cylinder by 16″ stroke, directly

connected, and making 350 revolutions per minute, giving a piston travel of 933 feet per minute.

The steam is supplied by eight Babcock & Wilcox boilers of 2000 aggregate horse-power, and which will work under a pressure of about 120 pounds. These occupy the basement of the building. Over them, the first and second floors being removed, an iron superstructure is erected entirely separated from the walls of the building, and on this the combined dynamos and engines are placed.

One-half of this equipment is now nearly ready for service, and the remainder is expected to be completed during the coming season.

The armature of the dynamo is of the form commonly known as the Siemens armature, but in its construction and "connecting up" it differs radically from all others.

The foundation of the armature, or the iron core which is built upon the shaft, is made up of sheet-iron disks, separated from each other by sheets of tissue-paper, and bolted together. This has all the advantages of a solid iron core in strengthening the magnetic field, while it completely prevents the great loss of power by local currents, which would circulate in the iron if it were solid. In the place of insulated wires, the cylindrical face of the armature is made up of heavy copper bars, trapezoidal in section, each bar being insulated, and also separated from its neighbors and from the iron core underneath by an air-space.

The connection between the bars on opposite sides of the armature, to form the electrical circuit, is made by copper disks, of the same diameter as the core. At each end of the core are one-half as many of these copper disks as there are bars, each disk being insulated from its neighbors, and the whole being bolted together in such a manner as to form, with the disks of sheet-iron constituting the core, one solid mass. Each disk is formed with projecting lugs on its opposite sides to which the two bars are connected.

The connections between the opposite surfaces of an armature are of no benefit in generating an electric current, but are a necessary evil, introducing useless resistance into the circuit. By using for this connection copper disks in the manner described, a great weight of copper is disposed in a limited space; and so this useless resistance, and consequent loss of energy, is reduced to a minimum.

This method, moreover, reduces the work to a simple machine construction, in which all the parts are duplicates, and the operations can be much cheapened and facilitated by the use of special tools.

The spaces between the armature bars admit of a free circulation of air, thereby preventing the accumulation of heat, and increasing to an enormous degree the capacity of the machine. The armature is at intervals wound with piano wire over the bars to resist the centrifugal force developed by their revolution.

The commutator and brushes of an electrical machine are the parts subject to the greatest depreciation. In this machine all parts of the end of the armature are so constructed as to be easy of access, and they can be quickly and cheaply repaired, or removed and replaced by new parts, when necessary. Any accident would require but a short stoppage for repairs.

Provision is made for keeping a continuous and rapid circulation of air over the entire face of the armature.

This armature is 27.8″ in diameter by 61″ long. The commutator adds 18″ to this length, and is itself 12¾″ in diameter. The armature shaft is of steel, 7¾″ in diameter, having a total length of 10′ 3″. The journals are 6½″ in diameter by 15″ long, and run in Babbitt-metal bearings, in pillow-blocks of the box form, giving the greatest stiffness with minimum of weight.

Provision is made for continuous water circulation underneath the boxes, and for continuous lubrication, with traps to prevent the creeping of the oil along the shaft and reaching the commutator, and drains to receive it as it runs through the bearings and convey it to a drip pan.

The magnet is made up of two immense cast-iron "pole pieces," between the semi-cylindrical faces of which the armature revolves, twelve cylindrical soft iron cores attached to these pole pieces, and made magnetic by an electrical current circulating in the wire around them, and four soft iron keepers connecting the back ends of these cores. Eight of the cores are attached to the upper pole piece, and four to the lower one.

The width of these poles is 49″, and their height 61½″. The length of the twelve soft iron cores is 57″, the diameter of the four upper ones is 8″, and of the eight lower ones 9″.

The four soft iron keepers are each 11″ wide by 9″ in thickness, and the total length of the magnet is 94″.

The magnet is insulated by cast zinc bases 3″ in thickness.

The weight of the dynamo is as follows:

Armature and shaft,	9,800 lbs.
Two pillow-blocks,	1,340 "
Magnet, complete,	33,000 "
Zinc bases,	680 "
Total,	44,820 "

The copper is distributed as follows:

In the armature bars,	590 lbs.
" " disks,	1350 "
In the magnet wire,	1500 "
Total,	3440 "

Mr. Edison was early impressed with the conviction that to give steady and reliable motion to these armatures it would be necessary to connect an engine to each one of them directly. This combination has been termed by him the Steam Dynamo.

In adapting the Porter-Allen engine to this service a special construction in some respects was found to be called for. These special features will be briefly described.

It seemed important to avoid a rigid connection between the engine and the armature shafts, which would require the entire series of bearings to be maintained absolutely in line. In place of this, therefore, a self-adjusting coupling (see Fig. 33) has been introduced, which will permit of considerable errors of alignment without any abnormal friction being produced in the bearings.

The point of difficulty was the backlash, the engine having no fly-wheel, except the heavy armature itself, which was to be driven through the coupling. Provision was made for taking this up by steel-keys of a somewhat peculiar form, between which the tongues of the coupling move freely, while they themselves are immovable. These keys are held between set-screws threaded in wrought-iron rings covering the flanges on the ends of the shaft. All the faces liable to move upon each other are oiled from a central reservoir. This coupling is a very compact affair, without a projection anywhere above its surface, and gives every promise of completely answering its purpose.

The engine is made with a forked bed and two shaft bearings and a double crank, and so is completely self-contained. It is shown in plan and elevation, Figs. 29 and 30.

The shaft having no support beyond these bearings on either side, unusual stiffness was required in the crank-pin to prevent deflection under the great strains to which it is subjected.

A novel form of pin (see Fig. 31) was proposed by Mr. Richards, which is found to possess all the rigidity required. It is provided with flanges, which are let into each crank, and held each by four screws, as shown, while the shanks of the pin are also forced firmly into the cranks.

Special appliances enabled the work of putting the cranks together in this manner to be done with extreme and uniform accuracy.

The engine is so arranged as to have the valve gear on the side furthest from the dynamo. The engineer has not to go between the engine and the dynamo, when running, for any purpose.

The connecting-rod (Fig. 32) is of steel, and the crank-pin boxes are formed directly in the end of it.

This end is finished from a solid forging, and chambered out for Babbitt metal. The bolts are then fitted, after which it is parted and holes are drilled for holding the Babbitt securely.

In the connecting-rods for single crank engines of this type permanent length of rod is secured by forming the crank-pin end solid, and taking up the wear by a wedge closing up the inside box. In these double crank engines this construction is impracticable, but the same object is attained by forming the cross-head end in the manner shown, in which the strap is made permanent, and the inside box is closed up by a key bearing against a steel plate.

The weight of the reciprocating parts of this engine is as follows:

Piston, with rod,	83 lbs.
Cross-head,	42 "
Connecting rod,	109 "
Total,	234 "

The initial acceleration of this mass, or the force required, on the dead centres, to give it the motion necessary to relieve the crank from strain is as follows:

$$350^2 \times .66 \times .000341 = 27.57,$$

or 27.57 times the weight of the mass, which gives

$$234 \times 27.57 = 6451 \text{ lbs.}$$

The formula is $R^2\ l\ c$, when

R = the revolutions per minute ;
l = the length of the crank in decimals of a foot ; and
c = the coefficient of centrifugal force.

The connecting-rod is 48″, or six cranks, in length. This affects the initial acceleration, making this to be on the dead centre farthest from the crank 7526 lbs., and on the dead centre nearest to the crank 5376 lbs., a difference of 40 per cent.

The area of the cylinder is 98.2 square inches.

The area of the piston-rod, $1\frac{3}{4}$ inches diameter, is 2.4 square inches, leaving area of cylinder at crank end 95.8 square inches.

The initial accelerating forces are therefore as follows, viz. : At the end of the cylinder farthest from the crank 77 lbs., and at the end of the cylinder nearest to the crank 56 lbs., on the square inch of piston area.

The counterweight was after some trials fixed at 135 lbs. This leaves 99 lbs. of the reciprocating parts running unbalanced. It is found that this is not sufficient to disturb the stability of the engine, while on the other hand the counterweight is not so great as to exert an objectionable strain in the vertical direction.

The total weight of the engine is 6,445 lbs.

The engine and dynamo are mounted on a cast-iron base plate, made for convenience in two parts, and bolted together.

The dimensions of this base plate are as follows : Length, 14 feet ; width, 8 feet 9 inches ; and its weight is 10,300 lbs. The entire weight is therefore as follows :

Base plate,	10,300 lbs.
Dynamo,	44,800 "
Engine,	6,450 "
Total,	61,550 "

The large engraving is a perspective view of the Dynamo and Engine combined. (Fig. 35.)

The last and most careful test of one of these dynamos gives the following results, as shown by the indicator diagrams, which are here reproduced full size ; scale, 80 lbs. to the inch.

The lamps used in all the trials were of the older construction, of which $8\frac{1}{2}$ lamps, at 16 candle-power incandescence, require one horse-power of electrical energy.

Since these were placed for experimental uses, improvements in the lamps have increased their economy, so that one horse-

power is sufficient to maintain fully 10· of the present lamps at 16 candle-power incandescence.

Diagram No. 1 (Fig. 34) shows the friction of engine and dynamo at 350 revolutions per minute, requiring 13.63 H. P.

Diagram No. 2 shows the resistance with the magnet circuit on = 19.17 H. P.

Field 5.78 ohms, 103 volts.

The increased resistance due to the magnets was 5.54 H. P.

Of this, the calculated energy developed in the magnets was

$$\frac{103^2 \times 44.3}{5.78 \times 33{,}000} = \quad . \quad . \quad . \quad . \quad . \quad . \quad 2.46 \text{ H. P.}$$

Leaving energy to be accounted for by local currents in iron core of armature, and in armature bars, 3.08 H. P.

Diagram No. 3 shows the work done in maintaining 300 lamps. These, in the ratio of $8\frac{1}{2}$ to 10, were equal to 353 lamps of the present construction. The pressure was maintained also at 102 volts, representing 25 candle-power, in place of 98 volts, representing 16 candle-power incandescence, which requires the number of lamps to be increased in the ratio of 102^2 to 98^2, or to 382 lamps.

The pressure of the armature was 104 volts, showing a loss in the conductor of 2 volts, which would increase the number of lamps as 104 : 102.*

The total correction is therefore as follows:

$$300 \times \frac{10}{8.5} \times \frac{102^2}{98^2} \times \frac{104}{102} = 389 \text{ lamps.}$$

The power exerted was 60.6 H. P., which gives to the indicated horse-power

$$389 \div 60.6 = 6.42 \text{ lamps.}$$

The magnet circuit had now a resistance of 5.28 ohms with 104 volts pressure, representing

$$\frac{104^2 \times 44.3}{5.28 \times 33{,}000} = \quad . \quad . \quad . \quad . \quad 2.75 \text{ H. P.}$$

Substituting this in place of 2.46 H. P. in the first trial, we have 19.46 H. P., which, deducted from 60.6 H. P., leaves net 41.14 H. P.

This gives $389 \div 41.14 = 9.45$ lamps per H. P.

* The conductors were insufficient, occasioning a loss that increased with the increase in the number of lamps.

Diagram No. 4 shows the work done in maintaining 700 lamps.

The pressure at the lamps was maintained, as in the preceding trial, at 102 volts, which required at the armature a pressure of 105 volts.

The total correction in this case is therefore

$$700 \times \frac{10}{8.5} \times \frac{102^2}{98^2} \times \frac{105}{102} = 919 \text{ lamps.}$$

The power exerted was 115.83 H. P., giving to the indicated horse-power $919 \div 115.83 = 7.93$ lamps.

The resistance of the magnet circuit was now 4.78 ohms, with 105 volts pressure, representing

$$\frac{105^2 \times 44.3}{4.78 \times 33{,}000} = \quad . \quad . \quad . \quad . \quad 3.1 \text{ H. P.}$$

Substituting this in place of 2.46 H. P. in the first trial, we have 19.81, which, deducted from 115.83 H. P., leaves net 96.02 H. P.

This gives $919 \div 96.02 = 9.57$ lamps per H. P.

Diagram No. 5 shows the work done in maintaining 1050 lamps.

The pressure at the lamps was maintained in this trial at only 99 volts, but this required at the armature a pressure of 108 volts, showing a loss of 9 volts in conduction.

The total correction in this case is thus

$$1050 \times \frac{10}{8.5} \times \frac{99^2}{98^2} \times \frac{108}{99} = 1375 \text{ lamps.}$$

The power was 168.4 H.P.

Giving to the indicated horse-power

$$1375 \div 168.4 = 8.16 \text{ lamps.}$$

The resistance of the magnetic circuit was now 3.28 ohms, with 108 volts pressure, representing

$$\frac{108^2 \times 44.3}{3.28 \times 33{,}000} = \quad . \quad . \quad . \quad . \quad 4.77 \text{ H.P.}$$

Substituting this in place of 2.45 H. P. in the first trial, we have 21.48 H. P., which deducted from 168.4 H. P., leaves net 146.92 H.P.

This gives $1375 \div 146.92 = 9.36$ lamps per H.P.

It will be seen that the losses of efficiency due to undiscovered resistances are only

In the first case, $10 - 9.45 = .55$ H.P. per lamp,

In the second case, $10 - 9.57 = .43$ H.P. per lamp, and
In the third place, $10 - 9.36 = .64$ H.P. per lamp,
Averaging 5.4 per cent.

The friction in the journals of the armature, when driven in this manner, does not increase with the resistance, and, on account of the action of the reciprocating parts of the engine, that in its bearings is also nearly a constant quantity, whatever the load may be.

The above figures show this very clearly, the subtraction of the friction diagram in each case exhibiting substantially the same net power per lamp.

Discussion.

Mr. Le Van: I would like to ask why they use Babbitt metal? I know that when I was a lad we used Babbitt metal because we had not the means of boring things properly. But in the present state of art I cannot see why the journal boxes should be made of Babbitt. I have never used it in my practice, and I never had a hot journal. I admit we do not run up to three hundred and fifty revolutions, but we do go as high as two hundred and fifty.

Mr. Porter: So far as my practice is concerned we use Babbitt metal in this case, because we use it in all cases. We have found it to answer our purpose admirably well. There may be some time when we shall see our way to using something better. But we do not feel as if we could try more than one experiment at a time, and we know precisely what Babbitt metal will do for us. It answers our purpose perfectly. We never have a warm bearing, and the Babbitt metal does not wear away. I do not see how we could run a steel connecting-rod with any other metal so well.

Mr. Le Van: I wanted to find out whether he puts the Babbitt metal into that box prior to cutting it apart, or afterwards.

Mr. Porter: Afterwards.

Mr. Le Van: Do you find any difficulty?

Mr. Porter: Not at all. A chamber is bored out. Of course we cannot drill the holes in the bottom of the chamber for securing the Babbitt until after the boxes are cut apart.

Mr. Le Van: I presume the indicator used is a Porter-Allen Indicator?

Mr. Porter: No, sir. The indicator is the Tabor Indicator.

Mr. Oberlin Smith: I would like to ask why it is found necessary to sacrifice simplicity by making a pair of independent journals for the engine; why the pillow-block of the dynamo could not have been run out into the main frame of the engine, in which case you would have the crank directly upon the end of the dynamo shaft.

Mr. Porter: The construction that Mr. Smith presents as an alternative, would be a crank on the end of a dynamo shaft, without any additional bearing whatever; that would lengthen the dynamo shaft considerably. It would be necessary to extend the dynamo shaft quite a distance to accommodate what is considered to be required between the engine and the dynamo. It would need to be two feet longer probably than it is now, and the shaft has to be subordinate to the armature. It was thought on full consideration, desirable to have the two entirely independent. The engine shaft can be taken out without affecting the dynamo. The dynamo can be taken out without affecting the engine. The armature is a very complicated construction, and the shaft on which it is built it is thought ought not to carry anything else whatever. There are other reasons also. In such a construction the engine would be a single crank engine, and the valve gear would have to be between the engine-bed and dynamo, which would not do.

Mr. Oberlin Smith: There may be electrical reasons for this construction. I only suggested the other as a matter of simplicity. The extra length of the dynamo shaft after all would not be as great as the aggregate length of the two pieces of engine shaft and the dynamo shaft now is. As a matter of construction, aside from electro-engineering, it would seem to be simpler.

The difficulty about the valve gear that Mr. Porter speaks of could be obviated by putting it *outside* the engine and driving it with what is known as an "eccentric crank." Any distance necessary to maintain between dynamo and engine, could be occupied by an extra-long main journal, which would be no disadvantage—rather otherwise. The armature could be lifted out, as it is now, having nothing foreign upon it but the crank, which is little larger than the present coupling. Disconnecting the boxes at crank-pin would be no worse than taking apart the coupling.

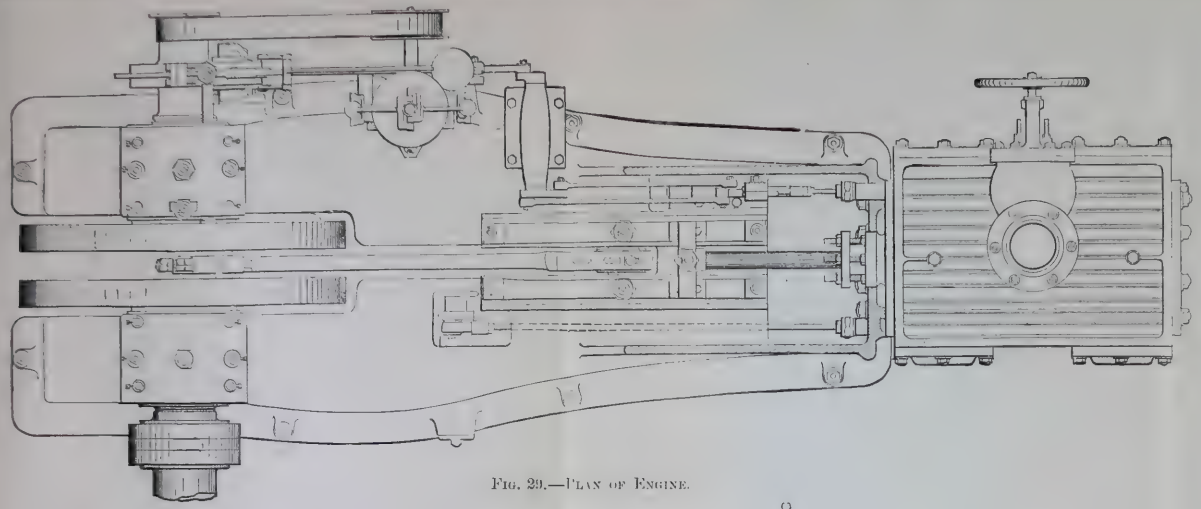


Fig. 29.—Plan of Engine.

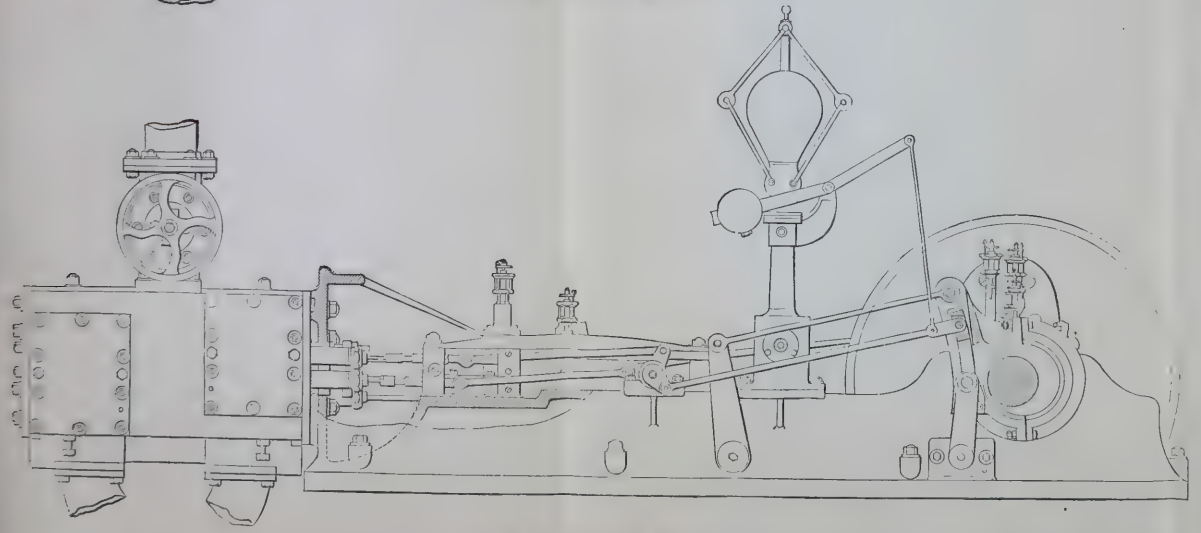


Fig. 30.—Elevation of Engine.

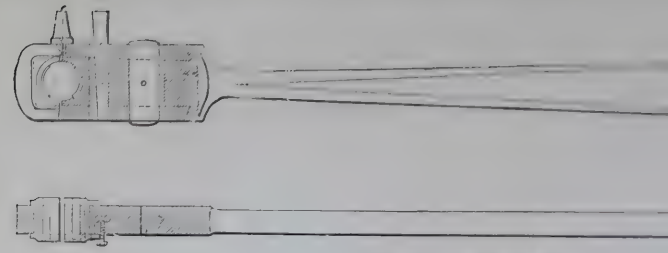
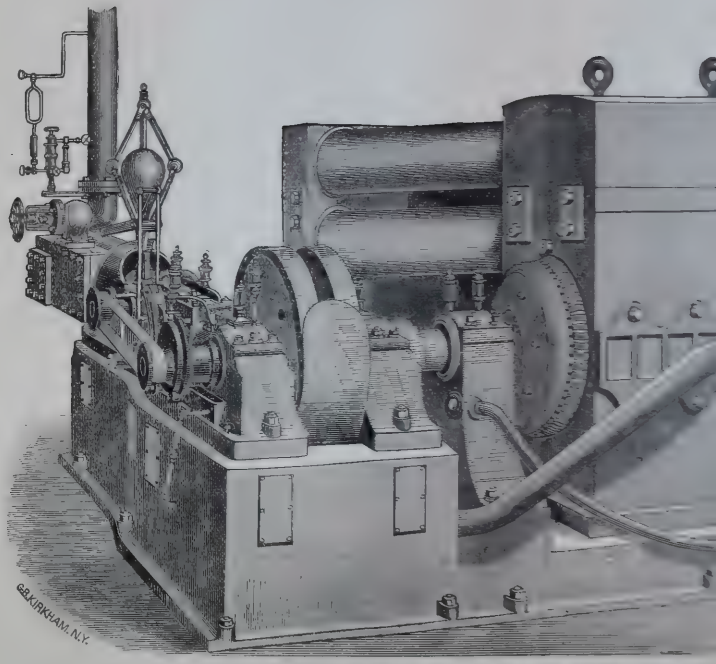


Fig. 32.—Connecting Rod.



Steam Dynamo (Dynamo and Engine Combined.
Fig. 33.

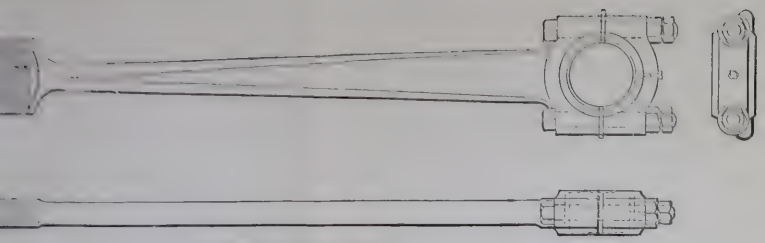
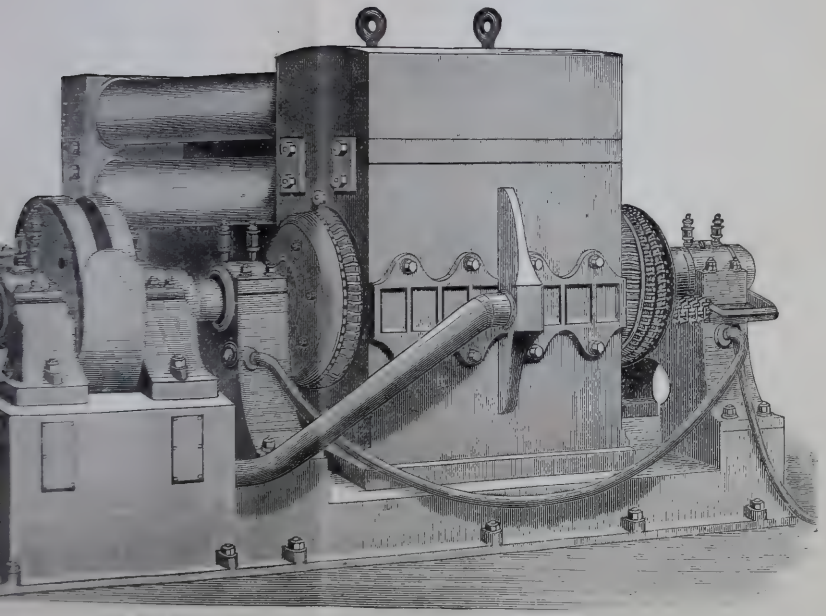


Fig. 32.—Connecting Rod.



Steam Dynamo (Dynamo and Engine Combined).
Fig. 35.

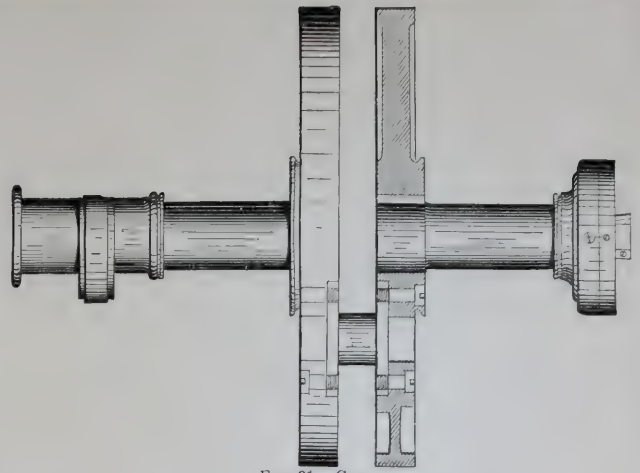


Fig. 31.—Crank.

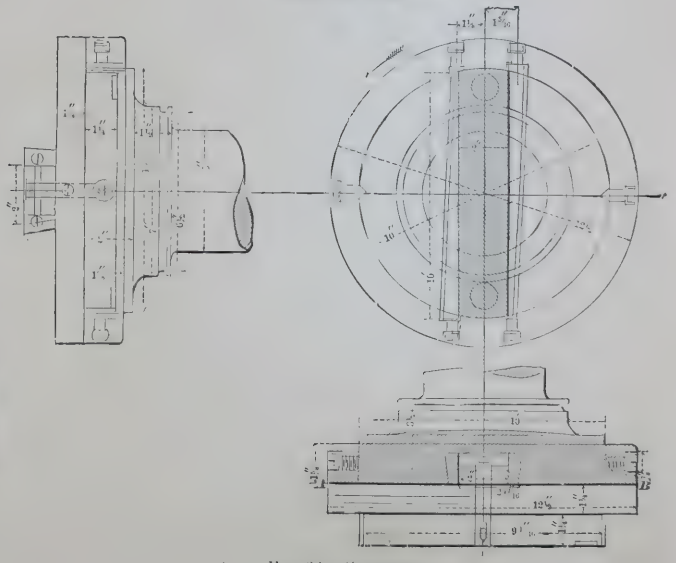


Fig. 33.—Coupling.

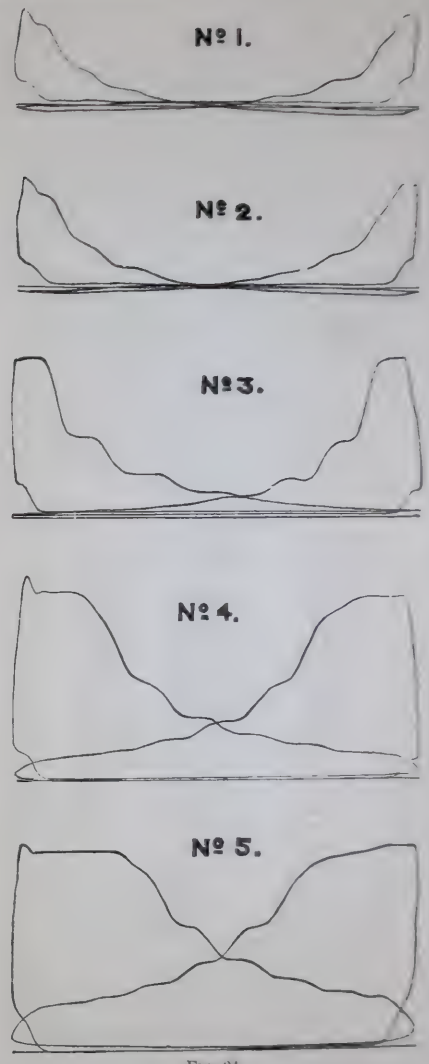


Fig. 34.

PROFESSOR THURSTON: I would like to ask Mr. Porter what pressure he can get on his Babbitt?

MR. PORTER: The pressure to the square inch?

PROFESSOR THURSTON: Yes.

MR. PORTER: I fancy it will stand anything.

PROFESSOR THURSTON: As much as bronze will?

MR. PORTER: It will flow, of course, where bronze will not, but I think we have had two thousand pounds on the square inch of Babbitt without having it flow at all. The Babbitt we use is made of copper, tin, and antimony, with twice as much antimony as copper.

MR. LE VAN: Babbitt's receipt is not as you mention. Probably you have a better mixture. I never found the Babbitt to stand as well as that.

MR. PORTER: I have forgotten our proportions exactly, but the amount of antimony is twice the amount of copper.

MR. LE VAN: I am satisfied that there are white metals that will carry strains better than Babbitt metal, and I think you have got one of those.

MR. BARR: There is a receipt in Haswell, and I would like to ask Mr. Porter whether the proportions he uses are the same as those given by Haswell, and if so we shall then know whether it is Babbitt's metal or something else.

MR. PORTER: I have forgotten the precise formula. I cannot answer the question. I have forgotten both the formula and the receipt given by Haswell. All that I remember is that we at one time employed equal proportions of copper and antimony, but wishing to make a harder metal we doubled the proportion of antimony. I don't carry figures very well in my mind. I ought to be familiar enough with that, but it has gone from me now. But the larger proportion of the alloy as everybody knows is tin.

LXXII.

NOTE ON THE ACTION OF A SAMPLE OF MINERAL WOOL, USED AS A NON-CONDUCTOR AROUND STEAM-PIPES.

BY

F. R. HUTTON, SCHOOL OF MINES, NEW YORK CITY.

THE samples exhibited to the society were taken from the outside of a five-inch steam-pipe, which carries steam at an average of 40 pounds pressure per square inch.

The pipe is one of three which lie close together, and are surrounded with a casing of galvanized iron. Inside this casing was packed the mineral wool which has acted on the pipe as shown. The casing was made in bandages, soldered together endwise, and at the joints. The only outlets were at the intervals where hanger rods hooked into rings on the pipes to support them. Where the pipes passed through the open air, it was possible for atmospheric moisture (fog, rain, or snow) to enter within the casing by trickling down the hanger rods. Where the piping was under cover, the moisture could only come from leakages at joints, or it might have been conveyed as steam along the tight casing. But so tightly was the wool packed in many places that long travel was prevented.

The samples were taken from a part of the pipe which it had become necessary to unsheath, where the run was under cover. Some are from the neighborhood of a flange-joint where a rubber gasket had deteriorated and permitted a slight leakage. Others are from a length of pipe which enters an elbow, where the expansion of a long run of pipe is concentrated. The flexing of this joint has caused the leakage, or else the moisture has come from a buried pipe which leaked underground some time before opportunity arose to repair it. In either case, the corrosion of the pipe seems to be the result of the action of mineral wool, when affected by moisture and heat. The intensity of corrosion may be inferred from the fact, that the threads of the pipe have been obliterated, partly by loss of top, no doubt, as well as by the filling in of the roots. These cakes may be lifted by the thumb-nail, where large. Smaller flakes are broken off by expansion and contraction.

The mineral wool, when sheathed in this way, seems to change its mechanical character when permeated by moisture. This change will be shown to be one result of a chemical decomposition. When dry it remains a non-adherent bulky and open mass all around the enveloped pipes. When it becomes wet—(it holds a great deal of water)—it becomes soggy, more compact, and falls away from the upper part of the sheathing, in some cases exposing the pipe. The saturation has been detected in one or two places by the deformation of the sheathing. Water may be squeezed out of the mass even after it appears dry.

To supplement the subject is exhibited a piece of $2\frac{1}{2}''$ pipe, which has been buried in mineral wool packed into a brick tunnel open at the ends. The top of the tunnel was flat, made of bluestone flags laid in cement, and covered all over with cement. Whatever moisture got into the tunnel should have evaporated outwards at the ends; but some did not, and has acted to corrode the pipe to great thinness on the lower side, and it was ultimately blown through at about the middle of its length. This pipe, as well as the five-inch pipe from which the scales were taken, were laid new and sheathed in the fall of 1879. They are, therefore, not quite two and a half years old. I have just dug up a 3″ pipe laid in the summer of 1874 in earth which is not particularly dry. It is as good and strong as ever, and has had just the same work to do as the sample shown. Both were return pipes from steam-heating systems, carrying condensed steam back to the boilers.

It has, therefore, become necessary to look for the cause of this rapid corrosion. The mineral wool is made by disintegrating blast-furnace slag by a jet of steam or air. The wool must, therefore, contain whatever constituents were in the slag, and will be as diverse in different samples as the charges in different blast furnaces. But the general composition must be a compound of silica with bases, usually lime, magnesia, etc. It may be expected, therefore, that some characteristics of one sample of such silicates, when it becomes wet, may be taken as likely to hold for all. It is a known fact that these silicates, under *heat and moisture*, will decompose into the hydrated silicic acid, or gelatinous silica, according to the chemical formula below (taking lime as probable base) $CaSiO_3 + 2.H_2O = Si(HO)_4 + CaO$.

The CaO is caustic lime, which mere dampness will slack, and

cause to attack any iron surface; or, if that reaction does not satisfy, it may be suggested that the decomposition of the wool sets free oxygen in what the chemists call a nascent state, in which state it will assault the iron as likely as the lime. But the specimen which I took and exposed to a few simple qualitative tests gave a strong reaction for hydrosulphuric acid—the characteristic acid of corroded eggs. The element sulphur is not at all an unusual one in slags. It may be present as combined in a sulphide, or in a hyposulphite, probably with lime as a base. In either case, moisture and heat would release sulphur as an oxidizing agent, which would be only too likely to fasten on the iron. Qualitative tests have shown the unmistakable presence of sulphur in solutions of scale taken from the pipe, thus proving that corrosion must have been more active than that due to an innocuous non-conductor, even though wet.

Where the wool has remained entirely dry, the pipes are as good as new. The white stencil of the tube works is as legible as ever at such points. The inside of the sample shown is free as ever from oxide, but where moisture is to be expected, on the outsides of pipes—as it must be in expanding and contracting runs of long pipe—it would seem necessary for the engineer to be very certain of the absence from his non-conductor, of such an agent as has been determined in this particular case, and to have his silicate in a form which will not decompose. The action would seem to be no less decided than in the cases where unleached ashes have been similarly used. The experience is, therefore, put at the service of the society for the protection of its members against similar mishaps.

Discussion.

Mr. Kent: I think this an exceedingly valuable paper. It will not only prevent us from using mineral wool in its present conditions, but it will teach mineral wool men to purify their products from deleterious elements. I must disagree, however, with the gentleman in regard to part of the chemical theory, the first part and the second part. As to the third part I partially agree with him. I think it is exceedingly unlikely that there is any decomposition of silicic acid or of any other earth. It is also extremely unlikely that caustic lime can be formed. It is also unlikely that oxide of calcium, if formed, would oxidize the pipe. The trouble is that the mineral wool lets in, somehow or

other, sulphurous acid gas. If you have a freshly made sample of this mineral wool, you smell it. You have present then sulphurous acid gas and sulphide of calcium. You may have sulphide of sodium and sulphide of potassium. You have free sulphurous gas. You will not have sulphuretted hydrogen at all, except by some subsequent decomposition. Sulphuretted hydrogen could not exist at a fusing heat. The chemical reaction that takes place is the oxidation of sulphurous acid into sulphuric acid by the oxygen of the water and air, especially in the presence of oxide of iron, or even free iron. I have made a synthesis to prove that sulphurous gas added to water, and that to iron, will oxidize it with tremendous rapidity, forming sulphate of iron, which will dissolve in impure water the same as this gentleman has found; the water solution of this iron will show sulphuric acid. You will find that recorded in the *Journal of the Franklin Institute* for 1875, in connection with the destruction of bridges due to the presence of sulphurous acid in the smoke from the coal burned on locomotives.

PROFESSOR THURSTON: I would like to ask Professor Hutton if it is proved that caustic lime will produce corrosion?

PROFESSOR HUTTON: I perhaps ought not to say proved. The hypothesis has been advanced that external corrosion of boilers set in lime mortar is the result of the calcination of that lime. I have taken that hypothesis for all that it is worth, and simply reproduce it in that form. I have no exact knowledge, no direct experiments to report on this subject.

PROFESSOR THURSTON: I asked the question because I have been accustomed to keep caustic lime in my cases with my iron to protect it from corrosion, and my object was not to secure the absorption of moisture, but to secure the absorption of the carbonic acid that might be present. I did not suppose that moisture would do any harm.

MR. WOODBURY: Is not the rusting of iron by mortar somewhat dependent on heat? We have wire lathing that does not rust, and in the blowers of mills where the nails run through there is no rust, but plaster of Paris will, of course, rust iron very rapidly.

PROFESSOR THURSTON: I presume that the mortar is never in perfect contact with the iron where corrosion occurs. There is a crack which holds the moisture, and that may lead to decomposition. I think Professor Calvert's experiments will throw a

good deal of interesting light on the matter. He investigated the reaction between oxidizable metals and gases, and as I remember now he never found oxidation occur at all where carbonic acid was not present. My theory has been in using caustic lime to prevent corrosion, as I say, that it should take up the carbonic acid. As long as it is purely caustic it will take up the moisture; after it is slaked it will do that no longer.

PROFESSOR HUTTON: My impression is, though, Mr. President, that the point as to the decomposition of silicates under heat and moisture is a patent fact, although I cannot myself give references to the subject. I have been told so. When this matter was brought to my mind I at once went to Professor Egleston, our Professor of Metallurgy at the School of Mines, and from him that statement of the decomposition of silicates comes. My own theory was the sulphate theory; I know by experiment that that is correct. This other theory is also advanced, but not directly upon my own authority nor my own experiments on which the discussion rests.

PROFESSOR THURSTON: As to the fact of corrosion there is, however, no doubt.

PROFESSOR HUTTON: There is no doubt about that.

PROFESSOR THURSTON: This reminds me of an interesting fact in connection with this paper. One of our members, who had had a very large experience in marine work, has been trying to get a non-conducting material for the protection of his boilers. I talked with him one day about some boilers he put in some of the Sound boats. He said he had given up there the use of hair-felt. He found that where he used it, corrosion was accelerated on the *inside* of the boiler. So seriously did it occur, especially about the steam-chimneys, he gave it up. He attributed it to hair-felt, and he satisfied himself by taking off hair-felt and replacing it with asbestos and other material, and shifting the position until he made up his mind that hair-felt did that.

MR. BARR: Did he say what particular kind of corrosion?

PROFESSOR THURSTON: I do not remember that he did. It thinned his boilers very considerably under these sheets of hair-felting, but he said it was so serious that he had given up the use of it.

MR. BARR: I wonder if he ever saw a steamship boiler that was not corroded in that way, whether hair-felting was used or not?

THE PRESIDENT: He is a man who I do not think would be mistaken on the subject, as he has very great experience.

MR. PARTRIDGE: It has been repeatedly stated that ordinary glass under the influence of heat and moisture is decomposed. It is certain that certain kinds of glass are easily corroded by moisture, though the process is a somewhat slow one. Old bottle-glass buried in the soil for a comparatively short time will show signs of corrosion; not unlike that of the ancient Greek glass in the Cesnola collection in the Metropolitan Museum. Though this action has not been very closely studied, the resulting surfaces are precisely similar to those obtained by the use of hydrofluoric acid in producing iridescent glass.

Why should not a similar decomposition take place with an imperfectly formed glass like mineral wool, in which there is likely to be a large excess of some of its constituents, especially those sensitive to the action of heat and moisture?

PROFESSOR EGLESTON: The paper which Mr. Hutton has just read is one of much interest, as blast-furnace wool is being used on a very large scale as a non-conductor. This is not the place to discuss the characteristics of blast-furnace slag, but a knowledge of a few of them is necessary in order to fully understand how it is likely to be affected. Blast-furnace slag from which the wool is made is not a material of constant composition; it varies not only in different districts, but with the same furnace under varying conditions. It is the only means by which the sulphur remaining in the ore can be removed in any appreciable quantity, and in furnaces running upon sulphurous ores the slag is made of such a composition as will contain as much as possible of the sulphur contained in the ore. While the slags are variable so far as their ultimate chemical composition is concerned, there are a few characteristics in which they are all alike; one of these is that they gelatinize with acids. It has been supposed until within a few years that silicates were not usually attacked except by the mineral acids; it is, however, known now that not only are other silicates attacked, but that all these silicates, forming blast-furnace slags, are attacked with great ease by organic and other acids, such as would be likely to be found in the ground. The sulphur, as will be seen in the analyses below, is in the slag mostly as a sulphide, probably of calcium.

ANALYSIS OF BLAST-FURNACE WOOL REMOVED FROM PIPES AT COLUMBIA COLLEGE.

Water,	1.08
Potash,	0.19
Soda,	1.75
Magnesia,	19.82
Lime,	26.56
Sesquioxide of iron,	0.64
Alumina,	7.84
Sulphur,	2.46
Silica,	38.97
	99.31

SOLUBLE IN WATER.

Water,	1.08
Potash,	0.19
Soda,	1.75
Magnesia,	0.12
Lime,	1.61
Sulphur,	0.23

INSOLUBLE IN WATER.

Magnesia,	19.70
Lime,	24.95
Sesquixoide of iron,	0.64
Alumina,	7.84
Silica,	38.97
Sulphur,	2.23
	99.31

ANALYSIS OF SCALE FROM PIPE.

Protoxide of iron,	3.98
Sesquioxide of iron,	81.51
Sulphuric acid,	3.75
Water,	4.38
Lime,	3.09
Magnesia,	1.07
Silica,	2.46
	100.24

After the slag has been exposed for some time to moisture the sulphur is transformed into sulphuric acid, attacking the iron or whatever other material there may be for it to attack. Moisture simply leaching through the slag would absorb sulphuric acid enough to give a decided reaction and to attack the iron. I have given above the composition of the wool as used around

the pipes, the parts which are soluble, and those which are insoluble in water before any action on the pipes commenced.

I have also given the analysis of the scale which was removed from the pipe, which shows that the action of corrosion on the iron was that of sulphuric acid. The slag transformed into wool does not differ at all from the slag in its solid form, except in the fact that it is capable of retaining a very large amount of air. To this and this alone is its non-conductive property due. It is, moreover, in this state much more easily attacked by any decomposing agent than when solid.

If this slag becomes packed in any way it loses a considerable portion of its non-conducting power, and if it becomes moist it loses still more, and is very likely to pack and become worthless. Heat and moisture will decompose the slag. The slag may become decomposed with the separation of gelatinous silica, and when heated, even slightly, in this condition would certainly attack the iron, not only as ordinary water attacks iron, but because it contains sulphates leached out.

Now, if in addition to this the pipes are buried in such way that they receive the superficial drainage, that exerts another more powerful action, for not only will the slag be attacked by the moisture, but the organic acids will further attack the slag and decompose it, rendering it entirely unfit for the purposes for which it is used. So long as the wool is kept dry and is not allowed to pack, there probably is no other substance that is as good for the purpose. The moment, however, that it becomes moist it is certain that the material then becomes dangerous to the pipes it covers. Those of us who are metallurgists have known of these facts for a long time. I made allusion to some of them in the Hartford meeting, when Mr. Emery announced his extremely interesting experiments on the conductivity of heat through various substances.

One thing must be understood from the accident which Mr. Hutton describes, that wherever blast-furnace wool is to be employed absolute freedom from moisture must be insured.

There are thus several inconveniences in the use of this material:

1°. If it becomes packed it loses its conductive power.

2°. If it becomes moist it sags together, becomes packed, and is worthless.

3°. If the moisture is at all constant there will be a decom-

position of the slag, and an attack on the iron by the sulphuric acid set free, or the organic acids if the material comes from the drainage of the soil.

It becomes, therefore, a matter of very great importance to engineers using this material, that they should prevent any of these different things from occurring; and then the material is one of the most valuable non-conducting substances known.

LXXIII.

ON A THEOREM OF RANKINE RELATING TO THE ECONOMY OF SINGLE-ACTING EXPANSION ENGINES, FIRST PUBLISHED IN 1851.

BY

WILLIAM P. TROWBRIDGE, PROF. ENG., COLUMBIA COLLEGE, NEW YORK CITY.

THE object of the theorem above referred to was, in the words of the author, "to investigate and explain the method of determining the rate of expansion, and consequently the dimensions and proportions of a Cornish engine which, with a given maximum pressure of steam in the cylinder, at a given velocity, shall perform a given amount of work at the least possible pecuniary cost, taking into account the expense of fuel and the interest of capital required for the construction."

He further states, as a fundamental proposition, that by increasing the ratio of expansion in a Cornish engine the quantity of steam required to perform a given duty is diminished, and the cost of fuel and of the boilers is lowered. But, at the same time, as the cylinders and every part of the engine must be made larger to admit of greater expansion, the cost of the engine is increased.

"It thus becomes a problem of maxima and minima to determine what ratio of expansion ought to be adopted, under given circumstances, in order that the sum of the actual cost of fuel and interest of the capital employed in construction may be the least possible as compared with the work done."

It is somewhat remarkable that this theorem is nowhere alluded to in the author's subsequent elaborate treatise on the steam

engine; while on the other hand he was the first to formulate in that treatise, definitely, the true theory of the efficiency of the steam in the cylinder of an engine, and to explain how the combined efficiencies of the boiler, engine, and mechanism are to be ascertained from a purely mechanical and theoretical point of view. During the thirty years that have elapsed since the publication of the theorem, its value and importance, if either can be attached to it, have been ignored not only by all eminent writers on the steam engine, but by those most interested, the designers and users of steam engines.

It is reasonable to suppose, from these circumstances, either that there is an inherent fallacy in the theorem itself, or that engineers and business men have found it to be, even if true as a mathematical proposition, inapplicable in designing engines, or in using them.

An apology ought to be offered for asking the further time and attention of this society to a subject upon which there can be very little difference of opinion among well-informed engineers, as far as its theoretical aspects are concerned; but in the recent renewal of the discussion, upon the basis of this old theorem of Rankine, such positive grounds are taken in regard to the necessity of a radical change of views and of practice among engineers concerning the proper method of ascertaining the conditions of maximum economy in the application of steam-power, that a thorough criticism of the new methods seems to be called for. In order to do this, it is necessary to enunciate the theorem in its mathematical form.

Let p_e represent the mean effective pressure in the cylinder of an engine per square foot of piston, and V_2 the volume in cubic feet generated by the piston in one hour; then $p_e V_2$ will represent in foot-pounds the work per hour of the weight of steam admitted to the cylinder. Let W represent this weight and h^1 the cost of producing it, including the cost of fuel, and the hourly interest on the cost of the boilers $\frac{h^1}{W} = h$ will be the cost of producing one pound hourly.

Let K^1 represent the total interest on the cost of the engine, A the area of the piston, and K the interest per hour of the cost of the engine per square foot of the piston, then

$$K^1 = K. A.$$

The assumption made is, that the work in foot-pounds divided by the cost of the work must be a maximum for greatest economy; that is, if y be this ratio

$$y = \frac{p_e V_2}{h.\ W. + K.\ A.} \text{ must be a maximum.}$$

Let l represent the length of stroke, n the number of revolutions per hour, r the ratio of expansion, then

$$W = \frac{A.l.n}{r} . D$$

D being the weight of a cubic foot of steam at the initial pressure.

The above expression then becomes

$$y = \frac{p_e V_2}{h. \frac{A.l.n}{r} . D + K.A.}$$

$$= \frac{A.l.n \left[\frac{p_1}{\gamma - 1} \left(\frac{\gamma}{r} - \frac{1}{r^\gamma} \right) - p_2 \right]}{h. \frac{A.l.n}{r\, v_1} + K.A.}$$

r only being supposed variable in the second member, and in which p^1 is the initial pressure, γ. the exponent of v in the equation of the adiabatic curve of expansion, $pv\gamma = p_1 v_1 \gamma =$ constant, and p_2 the back pressure.

The result of the operation for finding the maximum of y by the calculus is an equation between the values of V_2, K, h, A, and r, as follows, supposing y to be $\frac{10}{9}$

$$h \frac{A.l.n}{v_1} \left(p_1 r^{-\frac{10}{9}} - p_2 \right) = K.A \left[p_1 10 - 10 r^{-\frac{1}{9}} \right]$$

This result and the former expressions will be recognized as those given in a paper read at the Hartford meeting of the society by Messrs. Wolff and Denton, as being substantially the same as those of Rankine. In this expression v_1, represents the value of one pound of steam at the initial pressure p_1, and $\frac{1}{v_1} =$

D, D being the weight of a cubic foot of steam at the same pressure.

The usual mode of stating the efficiency of the steam in the cylinder of an engine is

$$E = \frac{p_e V_2}{H. \frac{A\,l\,n}{r} D. \times 772}$$

In this expression no element of cost enters, but the denominator represents the number of foot-pounds of work which enters, *as heat*, into the cylinder each hour.

H being the heat evaporation, $\frac{A.l.n}{r} D$ the weight W, and 772 the dynamic equivalent of a unit of heat. The maximum of this expression corresponds to such a degree of expansion by the adiabatic curve that the terminal pressure in the cylinder is just equal to the back pressure p_2. *The maximum of* y will correspond to a less degree of expansion, or to more steam used in proportion to the work developed.

The work $p_2\ V_2$ for any degree of expansion may be represented by a rectangle of which the base is V_2 and the altitude p_e. The denominator may also be represented by a rectangle having the same base, but with a much greater altitude. The efficiency E is the ratio of these rectangles, or what is the same thing, the ratio of the altitudes of the rectangles. A somewhat similar process may be applied to the ratio giving the value of y, as explained by Rankine and worked out for varying values of the mean effective pressures and for various engines and boilers by Messrs. Wolff and Denton in the paper above referred to.

The graphical process thus introduced by Rankine shows at once the ratio of expansion which gives the maximum of y, or the rate of expansion which gives the greatest number of foot-pounds for the least amount of money, according to the author, *when his assumed premises are accepted.*

In regard to the maximum of E, the mechanical efficiency, a discussion by Rankine, found in his work on the steam engine, is a legitimate and correct one, but the theorem which introduces the cost is, at least when applied to modern steam engines, fallacious, inasmuch as the *premises assumed are not true.* It is a very ingenious discussion, considered as a mere mathematical problem, admitting all the assumptions; but if these assumptions are not correct it must be considered, as it is

practically, mere play of mathematics without practical value. In this presentation of the matter from a purely theoretical standpoint, the secondary influences of cylinder condensation, clearance, etc., are not considered.

The first false assumption is in the total cost of making steam per hour, $h.W.$ $h.$ is a constant, and is the cost of evaporating one pound of steam, including interest on cost of boiler; and when multiplied by the weight W it is assumed that the cost of a boiler constructed to evaporate this quantity of steam varies with the quantity of steam produced.

Whereas it is well known that the *same boiler* will produce more or less steam depending simply on the draft, and upon other circumstances not introduced. No exact relation of a general nature exists between the cost of a boiler and the quantity of steam it produces. Moreover, the chimney, or other appliance for producing draft, is an essential part of the boiler, and its cost should be included in the cost of making steam. The relation of cost to the quantity of steam produced is thus still more uncertain.

In the discussion of Rankine's theorem, by Messrs. Wolff and Denton, and by Prof. Thurston, who adopts and indorses their discussion, the quantity h is made to include also hourly wages of firemen, coal-passers, interest, a redemption annuity, or sinking fund, for the whole *supposed* lifetime of the boiler, etc. This accumulated quantity, h, multiplied by the weight of steam used at different grades of expansion, is taken at the hourly cost of making the quantity of steam W. It is hardly necessary to dwell on the fallacy of these assumptions, as the error must be apparent from the above statement, which will scarcely be denied by those conversant with steam apparatus.

The second false assumption is in making the total cost of an engine proportional to the area of the piston.

The value of K in the formula is the interest on the cost of the engine divided by the area of the piston. It is well known that the cost of modern steam engines does not vary as the piston area, nor as the volume of the cylinder.

The following statement, taken from the yet unpublished records of the Tenth Census, has been furnished me by Mr. Charles H. Fitch, special agent of the census, who has been engaged under my direction in determining the statistics of engines and boilers.

Cylinder Capacity and Cost.

"The following table exhibits comparatively the relations of cylinder capacity, weight, and cost in steam engines of the horizontal plain slide-valve type, rated at from eight to one hundred horse power:

Cylinder capacity of Engine.	Ratio of stroke to diameter.	Price per cubic foot of cylinder.	Weight of engine per cubic foot of cylinder (lbs.).
0.19	2.00	$1,910 00	8,684
0.27	1.71	1,392 00	6,296
0.46	2.00	1,113 00	7,500
0.59	1.77	952 00	7,118
0.72	1.60	872 00	6,944
0.90	2.00	749 00	6,264
1.31	1.66	707 00	6,183
1.58	2.00	644 00	5,860
1.79	1.43	633 00	5,168
2.14	1.71	569 00	5,023
2.79	1.50	497 00	4,337
3.48	1.87	451 00	4,253
3.53	1.33	509 00	5,241
4.41	1.66	448 00	4,736
4.35	1.20	517 00	4,638
5.44	1.50	459 00	4,964

"It is obvious that no formula can truly exhibit the relative changes of price and capacity, which does not consider the actual sizes of engines compared. The examples cited present an unusual degree of uniformity, a line of engines rated at uniform piston speed, and of similar excellent workmanship and finish.

"Between different styles and qualities of engines there can be no very definite comparison. For the same cylinder capacity a finely built, closely fitted engine may cost twice as much as an engine of inferior workmanship."

Rankine evidently assumed that the cost is proportional to the volume of the cylinder or to piston area, because this is the only assumption that will enable an engineer to *design an engine with a given power*, the steam being cut off at the point of the stroke determined by his theorem.

He gives an example by designing an engine of 100 H.P., having first found the proper ratio of expansion for a cylinder having a unit area of piston and a given speed. He finds the cost of a 100 H.P. engine of the same speed to be by his process £6018, an assumed cost of £250 per square foot of piston. Of course, if his 100 H.P. engine, with all its appliances, was found, when actually constructed, to cost more or less than £6018 the whole process becomes invalidated.

It would seem that nothing more need be said to exhibit the fallacy of the assumptions or premises on which the mathematical work of the whole discussion is based. But we may place these fallacies on broader grounds.

There cannot be, from the nature of finance and pure mechanics, any exact mathematical relation between abstract mechanical laws and financial operations.

The former are invariable and immutable, the latter dependent upon bargain and sale, the efficacy of human labor, or upon human necessities, and sometimes on human follies.

No more conspicuous illustration of these truths, it seems to me, could be given than this plausible, but false application of mathematics, and especially of the calculus, to a problem in which the cost of an apparatus and its mechanical performance are introduced as elements of a formula which is claimed to be general in its nature and practically correct in its applications.

Looking at Rankine's theorem from another point of view it is claimed that although it is not applicable *for designing engines*, yet after an engine and boiler have been completed, and the actual cost of the whole plant is known, it is then practicable to determine for that engine the point of cut-off which will give the most power for the money already and actually expended.

Assuming, for instance, the principle that the power divided by its cost should be a maximum, the same mathematical expression

$$y = \frac{p_e V_2}{h.\ W + K.A}$$

is merely restricted to an apparatus of which the cost is known.

Taking this view of the problem the absurdity of including in any manner in the variable term of the denominator ($h.W$) the interest on the cost of the boiler, firemen's wages, insurance, depreciation of value from use, repairs, etc., is evident at once; because none of these items varies with the quantity of the steam used.

Moreover, it is not necessary to estimate the interest on the cost of the engine K by the square foot of piston, but the formula, admitting for the sake of argument its validity, should be

$$y = \frac{p_e V_2}{h.W + K}$$

in which $h.W$ includes only those items of cost which vary with the quantity of steam used, and in which K includes all the constant hourly expenditures of the plant, including boiler and engine. We should thus have to include in h only the cost of making one pound of steam per hour estimated from the price of coal, while K would necessarily embrace the following items:

1. Hourly interest on cost of boiler.
2. " " " engine.
3. " " " chimney.
4. " " " boiler room and engine room.
5. Wages of engineer and fireman per hour.
6. Insurance per hour.
7. Taxes per hour.
8. A portion of the wages of general foreman and manager per hour.
9. Estimated repairs per hour.
10. Sinking fund for redemption of cost of boiler and engine, estimated to last (blank) years.

Everything, in fact, must be included which can reasonably be charged to the cost of the power, as distinguished from expenditures for utilization of power and other expenses connected with it.

In this mathematical formula, for which it has recently been claimed that it furnishes "*the only correct solution which has ever been presented*," and that it is of "*immediate practical use*," we find all of these quantities.

Let us see how they are to be determined numerically:

Interest—Who shall establish the rate?

Cost of engine and boiler—What shall it include?

Boiler and engine room and setting—How shall the cost be separated from that of the rest of the plant, in a manufacturing establishment, or in a steamship from other parts of the structure?

Wages of engineers and firemen—What shall be done if these wages should happen to change from time to time?

Insurance—When a whole establishment is insured what part shall be charged to power?

Salaries of general foreman and manager—What part shall be charged to power?

Repairs—What amount shall be *estimated?*

Sinking fund—How *estimated?*

Who can estimate the life of a boiler or an engine?

All or nearly all of the above quantities can be assumed only by mere guesswork; there is not a shadow of a guide or a rule for most of them, not even the results of experience, which so often aid in the solution of practical problems.

If the quantities in the formula are arrived at by mere guess, and without experience to guide the person who guesses, of what value are the results?

There is one other important consideration which should not be lost sight of in applying this method to a given plant, viz., that not until all these questions of cost have been successively guessed at and thus established, and not until after the boiler and engine have been erected, and ready for running, will the manufacturer or the steamship owner know what power he has at his disposal. The power developed at the "business man's" economical point of cut-off depends on these items of cost, and he must accept what his guesswork has given him.

Possibly the power thus available will not run his works or his ship, and he may find that in attempting this mode of economy he is a greater loser in the end for want of sufficient power or from having too much power. The moment dollars and cents enter into a problem it ceases to be a mechanical and becomes a financial one; and in such problems there must always be two sides to the account.

A horse-power as power has no standard or intrinsic value; its value depends entirely upon its serving fully and precisely the objects for which it is employed.

A definite amount of power, just sufficient for performing a given work, has a certain value, where one-half or indeed any less power might be of no value, and more power might involve loss.

Steam-power is like a manufactured article, and the question of preventing waste in the manufacture, by high grades of expansion and costly engines, is one in which all the conditions and circumstances of the use of the power must be considered. It cannot be narrowed down to a mere ratio between the cost of the engine and the cost of the fuel, as is claimed in the new method.

The attempt to apply this new method to marine engines in public vessels, where no questions of interest and of profit and loss can enter, is not the least of the absurdities that have marked the discussion of the subject.

The introduction of the sinking fund idea as a part of the cost involves another absurdity, because the operation of a sinking fund is to reduce the principal of the debt, and the value of the quantity K, in the formula assumed as constant, is not a constant under this assumption, but a variable quantity, practically a vanishing quantity. Thus the validity of the mathematical discussion is destroyed, even if there were no other elements of unsoundness in the process. It seems to me unfortunate that crude ideas on this subject should have been put forth as the results of exact scientific investigation, and a theorem, practically abandoned by its author, invoked to persuade business men that our most eminent and successful engineers of the present day have been practically ignorant of correct principles regarding the economical use of steam.

Nothing tends more to bring science into disrepute with those engaged in industrial pursuits than the hasty announcement in the name of science of conclusions or results, as truths, which are merely personal and unverified speculations or false deductions from assumed and unproved premises.

LXXIV.

ON THE SEVERAL EFFICIENCIES OF THE STEAM-ENGINE, AND ON THE CONDITIONS OF MAXIMUM ECONOMY.

BY

ROBERT H. THURSTON.

Section 1. Methods and Principles.

1. *The Several Efficiencies of the Steam-engine.*

In the design of the steam-engine the mechanical engineer has frequent occasion to solve certain problems relating to its economical performance, and especially to determine what proportions of engine and boiler are best adapted to give maximum economy of fuel or of money under certain conditions precisely defined in advance. Such problems may usually be solved by the determination of the ratio of expansion producing maximum economy under the given conditions. The methods proposed by the writer for the solution of these problems form the subject of this paper.

Several problems of this character may be classed together, all of which relate to one or another of the "Several Efficiencies of the Steam-engine," as the writer has called them.

These "Efficiencies" are:

(1) *The Efficiency of Fluid.*—This is measured by the ratio of work done by the working substance to the mechanical equivalent of the heat expended on it. In the perfect engine this efficiency is measured by the quantity $\frac{\tau_1 - \tau_2}{\tau_1}$; the range of temperature worked through, divided by the maximum, initial, absolute temperature of the fluid entering the cylinder of the engine. In real engines great losses occur by incomplete expansion and by direct transfer of heat from induction to exhaust without production of work.

(2) *The Efficiency of the Machine.*—This is measured by the ratio of the quantity of work transmitted from the engine to the "machinery of transmission" to the work done upon the piston by the working fluid.

(3) In some cases the product of the efficiency of the fluid by

the efficiency of the machine is called the *Efficiency of the Engine* or of the System.

(4) *The Efficiency of the Furnace* is the ratio of quantity of heat transferred to the working substance to that developed by the fuel.

(5) The *Total Efficiency of the Apparatus, or of Plant*, as the writer would term it, is the product of these several partial efficiencies, and is the fraction of the total calorific power of fuel which is delivered to the machinery of transmission as mechanical energy.

(6) *The Efficiency of Capital*, or the Commercial Efficiency of Steam Machinery, is measured by the amount of capital employed, or of the total running expenses per unit of a given power required and obtained; *i. e.*, it determines how small a sum will provide a given amount of power and *what size of engine must be selected for the given work.*

Each of the above efficiencies is made a maximum by a set of conditions, the determination of which constitutes an important problem in the science of engineering. Each must be solved, and in a certain definite order, before the engineer can feel perfectly confident of full success in the application of steam power to any given case. The determination of the efficiency of fluid is included in the problem relating to efficiency of engine, and this and all other efficiencies are included in the last,—the Efficiency of Capital,—which cannot be exactly determined unless they are first ascertained.

(7) In addition to the above, another problem may present itself to the user of power, although seldom to the designer, or to any one proposing to purchase a steam-engine,—the determination of the maximum economy of a given plant; *i. e.*, how the most work may be obtained for a dollar from a given engine already constructed. This is entirely a different problem from (6); its solution leads to very different results, and does not usually, if ever, determine maximum commercial efficiency, as will be seen later. Here, then, the problem relates to what may be called the "*Maximum Commercial Efficiency of a Given Plant.*"

(8) It may, finally, be necessary to determine still another question: "*What is the Maximum Amount of Power that can be profitably obtained from a Given Plant?*" This is a more commonly familiar problem than the last, and of more direct and practical importance in most cases.

2. *Furnace and Boiler Efficiencies.*

The first case which naturally presents itself to the designing engineer, that relating to *Efficiency of Furnace or of Boiler*, has been frequently studied, and is well understood. To secure maximum efficiency, the engineer must provide for:

(1) Complete combination of fuel and oxygen without excess of air supply.

(2) Rapid and concentrated combustion.

(3) Rapid and general circulation of the heating-gases and of the heated fluid.

(4) Ample area of well-arranged heating surface to transfer heat from the furnace gas to the water.

In the case of a steam-boiler, efficiency is a function of area of heating surface and of quantity of fuel burned on the given area of grate surface. Rankine deduces the expression

$$\frac{E}{E'} = \frac{B}{1 + \frac{AF}{S}}$$

in which $\frac{E}{E'}$ is the ratio of water evaporated per pound of fuel to that which would be evaporated were the whole calorific power of the fuel utilized. Then

$$E = \frac{BE'}{1 + \frac{AF}{S}}; \quad S = \frac{FA}{\frac{BE'}{E} - 1}$$

S is the area of heating surface per unit of area of grate, and F the number of pounds of fuel burned per hour per square foot of grate. The constant B is, for bituminous coal, burned in good boilers, about 1; A varies from 0.3 with forced draught to 0.5 with chimney draught, probably varying nearly as the square of the weight of air supplied the fuels. Where a forced circulation has been obtained, the writer has found a lower value even than 0.3. In experiments with anthracite coal he has usually obtained a lower value of B than is given above, varying from 0.85 to 0.90.

The engineer, in using the above formula, usually decides what efficiency he can afford to pay for, and then obtains the value of S and thus determines the size and weight of his boiler; he rarely makes $\frac{E}{E'}$ exceed 0.75, and will often find it best to

accept a much lower value in order to obtain maximum commercial efficiency. This case should be treated similarly to that relating to the commercial efficiency of engines described hereafter at some length.

It will be found that the maximum commercial efficiency of boiler—*i. e.*, the proportion of heating surface to grate surface or to fuel burned on the grate per hour, which gives the required amount of steam at least total expenditure—is determined by the equations,

$$S = A' F \sqrt{R}; \quad \frac{S}{F} = A' \sqrt{R};$$

in which S is the area of heating surface per unit of area of grate; F is the weight of fuel burned on that unit of area; A' is a coefficient varying from 0.5 with boilers of quick or forced draught and good circulation to 0.7 with boilers having sluggish draught and a less perfect circulation; R is the quotient obtained by dividing the sum of all annual expenses, dependent on amount of fuel burned, reckoned per pound of fuel and per square foot of grate, by the sum of all the annual expenses per square foot of heating surface per unit of grate area, so far as they are dependent upon size and character of boiler; as interest, repairs, and depreciation. *E. G.*—For a usual case in marine practice, $A' = 0.5$; $F = 12$; $R = 26$; $S = 30$. For a case of continuous operation of boiler, as in a flour mill, $A' = 0.6$; $F = 10$; $R = 25$; $S = 30$. For certain cases of occasional use, as in a steam yacht, $A' = 0.7$; $F = 12$; $R = 10$; $S = 28$; $A' = 0.6$; $F = 10$; $R = 8$; $S = 17$.

R sometimes becomes as great as 50 in ordinary practice, when fuel is expensive.

The proportions of boilers of any given class are seen to be dependent solely upon the quantity of fuel burned, and the relation existing between the two classes of expenses—those of operation and those of maintenance.

When the boiler is once constructed and set, it is sometimes found possible to use profitably a larger quantity of steam than it was designed to furnish, and it may become a matter of interest, if not of importance, to determine what amount of steam will give the largest quantity per dollar of total running expense. In such a case, the boiler is worked with a more rapid draught, and more fuel is burned on the grate, other conditions affecting

efficiency being constant except as dependent upon the quantity, F, which now becomes the independent variable. The total cost of steam now becomes the sum of all expenses, constant and variable; and, calling K the annual cost of all items invariable with variation of quantity of coal burned, and $k = \frac{K}{G}$, this cost divided by area of the grate, it will be found that the "Maximum Commercial Efficiency of Plant," as the writer calls it, will be obtained when

$$F = \sqrt{\frac{k S + D S^2}{A C}};$$

when D is the annual cost per unit of S, as before, of items variable with S; and C is the annual cost per unit of F, of items variable with F. The boiler may often be profitably forced still further, until the cost of working no longer allows a profit on the steam made and used; but this limit may be reached either at or beyond the value of F, just deduced; it is found when, if k, C and D measure the cost of constant items of expense per unit of grate area of variable expenses for fuel and for boiler, and M is the *value* of steam, per unit of weight,

$$k G + C F G + D G S = M F G E$$

i. e., when the sum of all expenses becomes equal to the total *value* of the steam made. The analysis covering these cases will be given in a later paper.

3. *Efficiency of Engine.*

The Efficiency of Engine has been often studied by authorities accepted as standard, but almost invariably as a problem in thermo-dynamics, simply; and the losses of heat occurring in consequence of the working of steam in a cylinder composed of a good conductor of heat have been left unnoted although frequently the most important of all the expenditures of heat taking place in the engine. Mr. D. K. Clark discovered this phenomenon in 1851, and described it clearly in his papers and later publications. Professor Rankine noted this method of waste, and describes the phenomenon fully as early as 1859,* but neither he nor any other writer, Clark and Hirn excepted, for many years, seems to have realized the extent and importance

* Steam-engine, etc., § 286; par. 2.

of this loss in all engines.* Prof. Cotterill alone, of all authors known to the writer, has treated this part of the problem of steam-engine efficiency in a manner that is at all practically satisfactory to the engineer.†

The writer has endeavored in an earlier paper‡ to show what conditions determine maximum efficiency of fluid and of engine. In a non-conducting cylinder, the maximum Efficiency of Fluid would be secured if the ratio of expansion were made nearly equal to the quotient of initial by back pressure; $r^n = \frac{p_1}{p_3} = \frac{p_1}{p_2}$, while the efficiency of engine would be made a maximum when the ratio is made nearly equal to the quotient of initial pressure by the sum of all useless resistance; $r^n = \frac{p_1}{p_b} = \frac{p_1}{p_2}$. When, however, as is always the case in practice, the steam is worked in a metallic cylinder, the best ratio of expansion is made very much smaller, and the efficiency of the engine is greatly reduced by cylinder condensation and re-evaporation, which produce a serious waste of heat. The extent of this modification has been indicated by the writer, and an attempt has been made to determine by a simple method based on experiment and observation what are the usually best ratios of expansion, and what the least probable quantities of steam and of fuel demanded per hour and per horse-power, at maximum efficiency by the principal standard types of engine.

In a still later paper§ the writer has exhibited at great length the differences in the behavior of steam expanding in a non-conducting vessel, and in the metal cylinder of the steam-engine, and has shown how to determine and construct true "Curves of Efficiency" for actual engines, exhibiting the character of this newly discovered curve, and its functions. It was shown that the total loss of efficiency of work, or of pressure, due to cylinder condensation, may be allowed for by taking for its value the expression $a\, r^m$, in which a is constant dependent upon the state

* Proc. Inst. Mech. Engrs., 1852; Railway Machinery, 1855: Handbook for Mech. Engrs., 1877.

† The Steam Engine considered as a Heat Engine; J. H. Cotterill, London and New York, 1878.

‡ On the Ratio of Expansion at Maximum Efficiency. Trans. Am. Soc. Mech. Engrs., 1881; Journal Franklin Institute, May, 1881.

§ On the Behavior of Steam in the Steam Engine, etc. Jour. Frank. Inst. Feb., 1881.

of the steam before expansion, r is the ratio of expansion, and $_{m}$ is an exponent dependent upon the method of variation of the proportions of the mixture of steam and water as expansion progresses.

The useful work per stroke is a maximum, and the ratio of expansion at maximum efficiency of engine is found, when the latter is of such value as to satisfy the equation:

$$r^{-n} - a\, r^{m-n} = \frac{p_b}{p_1}, \text{ nearly,}$$

and when, if c is the "cut-off"

$$c^{n} - a\, c^{n-m} = \frac{p_b}{p_1}, \text{ nearly.}$$

The value of the constant a varies from 0.1 to 0.2, in good engines, according to quality of steam supplied, and $_{m}$ may be taken at 0 in the best cases of well-designed compound engines, and as rising to 0.5 in unjacketed single cylinder engines; n is the exponent in the equation of the expansion line.

Studying these modified conditions as observed in practice, the best rates of expansion for maximum duty r_e^1, for several well-known and typical classes of engines are taken by the writer thus:

Probable Terminal Pressures and Rates of Expansion at Maximum Efficiency.

Case.	Initial Pressures. *Absolute.*		Speed of Piston.		SINGLE CYLINDERS. Class I.—Non-condensing. Unjacketed.			SINGLE CYLINDERS. Class I.—Non-condensing. Jacketed.			SINGLE CYLINDERS. Class II.—Condensing. Unjacketed.			SINGLE CYLINDERS. Class II.—Condensing. Jacketed.			COMPOUND CONDENSING. Class III. Sides jacketed.			COMPOUND CONDENSING. Class III. Heads and sides jacketed.			COMPOUND CONDENSING. Class III. Heads and sides jacketed with efficient superheating.		
					$p_t = p_v$		r_e'	$p_t = p_v$		r_e'	$p_t = p_v = p_c$		r_e'	$p_t = p_v = p_c$		r_e'	$p_t = p_v = p_c$		r_e'	$p^t = p_v = p_c$		r_e'	$p_t = p_v = p_b + p_f$		r_e'
	P_1	P_m	V	V_m	Lbs. on sq. in.	Kilos on sq. cm.		Lbs. on sq. in.	Kilos on sq. cm.		Lbs. on sq. in.	Kilos on sq. cm.		Lbs. on sq. in.	Kilos on sq. cm.		Lbs. on sq. in.	Kilos on sq. cm.		Lbs. on sq. in.	Kilos on sq. cm.		Lbs. on sq. in.	Kilos on sq. cm.	
I.	40	2.8	400	122	20	1.4	2.0	20	1.4	2.0	16	1.1	2.5	13	.9	3.0	.9	.6	4.5	$7\frac{1}{2}$	.5	5	$7\frac{1}{2}$	.5	5
			625	185	20	1.4	2.0	20	1.4	2.0	13	.9	3.0	13	.9	3.0	.9	.6	4.5	$7\frac{1}{2}$	.5	5	$7\frac{1}{2}$	.5	5
II.	60	4.2	400	122	20	1.4	3.0	20	1.4	3.0	20	1.4	3.0	15	1.1	4.0	1.1	.8	5.5	8	.6	7.5	$7\frac{1}{2}$	.5	8
			625	185	20	1.4	3.0	20	1.4	3.0	15	1.1	4.0	15	1.1	4.0	1.1	.8	5.5	8	.6	7.5	$7\frac{1}{2}$	.5	8
III.	80	5.6	400	122	23	1.6	3.5	20	1.4	4.0	23	1.6	3.5	18	1.3	4.5	1.3	.9	6.5	9	.6	9	$7\frac{1}{2}$	.5	11
			625	185	20	1.4	4.0	20	1.4	4.0	18	1.3	4.5	18	1.3	4.5	1.3	.9	6.5	9	.6	9	$7\frac{1}{2}$	.5	11
IV.	100	7.0	400	122	25	1.8	4.0	20	1.4	5.0	25	1.8	5.	20	1.4	5.0	1.4	1.1	7.0	10	.7	10	$7\frac{1}{2}$	.5	13
			625	185	20	1.4	5.0	20	1.4	5.0	20	1.4	5.	20	1.4	5.0	1.4	1.1	7.0	10	.7	10	$7\frac{1}{2}$	.5	13
V.	120	8.4	400	122	27	1.9	4.5	22	1.5	5.5	27	1.9	4.5	22	1.5	5.5	1.6	1.1	7.5	11	.8	10.5	$7\frac{1}{2}$	.5	17
			625	185	22	1.5	5.5	22	1.5	5.5	22	1.5	5.5	22	1.8	5.5	1.6	1.1	7.5	11	.8	10.5	$7\frac{1}{2}$	.5	17
VI.	150	10.5	400	122	30	2.1	5.0	25	1.8	6.	30	2.1	5.0	25	1.3	6.0	1.8	1.3	8.5	12.5	.9	12	$7\frac{1}{2}$	.5	20
			625	185	25	1.8	6.0	25	1.8	6.	25	1.8	6.0	25	1.1	6.0	1.8	1.3	8.5	12.5	.9	12	$7\frac{1}{2}$	.5	20
VII.	200	14.1	400	122	36	2.6	5.5	29	2.1	7.	36	2.5	5.5	29	2.1	7.0	2.0	1.4	10.0	14	1.0	14	$7\frac{1}{2}$	.5	27
			625	185	29	2.1	7.0	20	2.1	7.	29	2.1	7.0	29	2.1	7.0	2.0	1.4	10.0	14	1.0	14	$7\frac{1}{2}$	.5	27

The terminal pressure $p_t = p^v$ is taken as equal to $p_3 + p^f$, the sum of back pressure and frictional resistance in non-condensing engines with low steam, and in highly superheated steam-engines.

Deduct 14.7 lbs. per sq. in. = 1 kg. per sq. cm. to obtain gauge pressures. Hyperbolic expansion is here assumed.

P_1 p^m are pressures in British and metric measures; V V_m are velocities in the same measures.

The probable minimum expenditure of steam per hour and per horse-power were also given as follows in the first of this series of papers:

Probable Minimum Weights of Steam per Hour per Horse-power.

r	W Pounds.	W_m Kilos.	r_e	W Pounds.	W_m Kilos.	r_e	W Pounds.	W_m Kilos.
3	32	15	8	20	9	13	17	8
4	27	12	9	19	9	14	16	7
5	25	11	10	19	9	16	16	7
6	22	11	11	18	9	20	15	7
7	20	9	12	17	8	25	15	7

Taking the probable minimum expenditure of coal per hour and per horse-power at *one-ninth* the weight of steam demanded, we get at the ratio of expansion giving a minimum cost of steam, the following:

Probable Minimum Weights of Coal per Horse-power per Hour.

r_e	W' Pounds.	W'_m Kilos.	r_e	W' Pounds.	W'_m Kilos.	r_e	W' Pounds.	W'_m Kilos.
3	3.5	1.6	8	2.2	1.0	13	1.9	0.9
4	3.0	1.4	9	2.1	1.0	14	1.8	0.8
5	2.8	1.3	10	2.1	1.0	16	1.8	0.8
6	2.3	1.1	11	2.0	0.9	20	1.7	0.8
7	2.2	1.1	12	1.9	0.9	25	1.7	0.8

For cases in which the boiler gives an evaporation of ten pounds of water per pound of coal we may get ten per cent. better figures.

The Efficiency of the Apparatus is the product of efficiency of furnace and boiler, the efficiency of engine, and the efficiency of mechanism of transmission. It is made a maximum when each of its factors is a maximum.

4. *Efficiency of Capital.*

The Efficiency of Capital, Case 6, is the most interesting of this series of problems of maximum efficiency, and its solution, by a practically correct method, giving reliable results accordant with experience, has been, by some engineers, regarded as one of the most important of problems now demanding the attention of the engineer. It is this problem which is proposed as the principal subject of the present paper.* In studying the efficiency of capital, it is first necessary to consider the elements of cost of power. The problem may be stated thus: *Given* the quantity of power required, to determine what ratio of expansion and what size of engine will give that power at minimum cost.

To solve this problem the engineer must know the cost of the engines, boilers, and appurtenances, and all items of running expense. Then making the sum of both items of variable annual expense—those variable with size of engine, and those variable with quantity of steam demanded—a minimum, the sum of these items and of all invariable expenses, *i. e.*, of the total running expense, becomes a minimum, and the problem is solved. A knowledge of these conditions and of all other expenses, constant as well as variable, is also essential to the treatment of Case 7, which may be thus stated:†

Given the size, power, and all items of cost, and running expenses of a known plant of steam machinery, to determine what method of working the steam, *i. e.*, what ratio of expansion, will give most work for a dollar of total expense of operation.

Since the economy of fuel and steam demands the use of a large engine, working steam with a considerable expansion, and gives reduced size and weight of boiler, it is evident that the first of these two problems is to be solved by determining what proportion of engine and boiler will be cheapest when summed up at the end of the life of the plant; this is settled when the ratio of expansion at maximum commercial efficiency is known, since the best size of engine and boiler is then fixed. The work may be done either by a large engine and a small boiler, or by a smaller engine supplied with more steam by larger boilers.

* This problem was first enunciated by Rankine, and solved for the case of the non-conducting cylinder.—*Vide* "Phil. Mag.," 1854; "Miscell. Papers," p. 295.

† First treated, so far as the writer is aware, by Messrs. Wolff and Denton, who solved it for the ideal case.—"Trans. Am. Society Mech. Engrs.," 1880; "American Engineer," 1881.

The second problem, Case 7, is solved by determining what degree of expansion will give most power from an engine and boiler already installed, at least cost per horse-power. The first problem contains, as elements, all items of cost variable with change of proportions of engines and boilers capable of doing the same given quantity of work. The second problem considers every item of expense, and the amount of power is a variable quantity. Both problems require the study of the costs of steam power and the determination of the way in which each is related to total expense, and the manner in which each varies with variation of the variable quantities in either case.

If, therefore, we have given a certain annual invariable expense of operation, certain additional expenses variable with size of engine, and therefore with the ratio of expansion, r, adopted, and certain other additional expenses variable with quantity of steam demanded and with size of boiler needed, and thus also dependent upon the ratio of expansion at which that steam is used, we may call the two latter quantities, respectively, $f^{\text{I}}(r)$ and $f^{\text{II}}(r)$, while the constant part may be called C. Then the total annual expense is $f^{\text{I}}(r) + f^{\text{II}}(r) + C$, which is a minimum when the variable part, $f^{\text{I}}(r) + f^{\text{II}}(r) = f(r)$ is a minimum, and this is a minimum when its ratio to work done, $F(r)$, is a minimum, *i. e.*, when $\frac{f(r)}{F(r)}$ is a minimum, or $d\,\frac{f(r)}{F(r)} \div dr = 0$. The value of r which satisfies this condition gives Maximum Commercial Efficiency.

The determination of the value of r which makes $\frac{f(r) + C}{F(r)}$ a minimum, gives the solution of Case 7.

Case 8 is solved by determining at what ratio of expansion the cost of power becomes equal to the market value of the power, less a paying profit.

The Annual Cost of Steam Power consists:

(1) Of certain expenses, which, in any given case, are usually invariable, whether the work is done by a large engine with high ratio of expansion and small boilers, or with a smaller engine working at a low rate of expansion and with larger boilers. These are usually: rent of building or interest on cost, taxes, repairs, etc., etc., of structure and location, the engineer's salary, and sometimes all or part of the fireman's or stoker's, also sundry minor expenses or a part of each of other expenses

which, as a whole, are variable. Both of the latter classes may usually be neglected in solving the problem here first considered.

(2) The interest on first cost of engine in place, the cost of repairs, and a sum which measures the depreciation in value of the machine due to its natural wear, or to its decreasing value in presence of changes that finally compel the substitution for it of an improved engine. Oil, waste, and other engineer's stores fall under this head. These items are variable with size and style of engine.

(3) The expenses of supplying the engine with steam. These are:

(*a*) The cost on fuel account of the steam supplied, and which includes, also, the cost of steam condensed *en route* to the engines and wasted by cylinder condensation and leakage, as well as that actually utilized. This total quantity of steam greatly exceeds that actually used in the production of power by simple transformation of heat energy. This item varies with the efficiency of engine and size of boiler demanded.

(*b*) The account of interest on cost of boilers in place and of their appurtenances, rent of boiler-room, depreciation, repairs, and insurance, which latter account is wholly chargeable to boilers. This is also variable with size of boilers.

(*c*) Cost of attendance in excess of the costs included in the constant quantity in item (1) and variable with size of boiler or quantity of steam demanded.

The salary of the engineer is usually not chargeable to either engine or boiler; his position is one of supervision over the whole apparatus, and a good engineer generally keeps the closest watch over the boilers. The engine can usually be trusted, much of the time, to take care of itself. With small engines, the engineer is also the fireman. With large engines, the number of regular firemen—or, at least, the number in excess of one attendant—may be taken as proportional to the quantity of steam demanded when working at ordinary power, and with very large marine engines the same remark may sometimes apply to engine-room attendance.

In recapitulation:

(1) In working up this account it will be most convenient, as will be presently seen, to refer all costs to volume of cylinder, and to so express variable quantities that they may enter our equations in terms of the ratio of expansion, which ratio is to

be taken as hereafter shown, as an independent variable upon which all other variable quantities are made dependent. We will enter all constant quantities as so many dollars of *annual* expense; the total, invariable expense will then be A', where A' includes all such expenses, whether chargeable to the engines or boilers, or to both.

(2) The cost of an engine varies according to no definite rule, and differs greatly with type of engine, kind of valve gear, character of work and value of material and labor, both at the manufactory and at the place of installation. With certain standard forms of engine, if large, it is found that the cost to the builder may be reckoned as very nearly proportional to volume of steam-cylinder, and his prices may be fixed on that basis. The cost of transportation, other things being equal, may often be similarly estimated, as may expenditures for repairs, engineer's supplies, etc., although these items are less exactly determinable.

It is here assumed that interest on cost of engine in place, depreciation, repairs, and all other expenses variable with size of engine, are to be reckoned per cubic foot of cylinder. This method is, in the opinion of the writer, more nearly correct than any other system of charging to this account that he has considered, and its probable error will be certainly unimportant for the small range met with in the usual case here studied.

(3) The cost of steam supplied to the engine, exclusive of the constant quantity entered in (1) may be safely reckoned as a certain number of dollars per pound or per cubic foot of steam worked in the cylinder.

The weight of steam supplied for the performance of work—when the weight per cubic foot of steam at the given pressure, p, is w, and its volume is $v_1 = v_2 \div r$—where r is the "real" ratio of expansion, is $w\,v_1 = \frac{w\,v_2}{r}$; its cost per cubic foot of steam cylinder is $\frac{k\,w\,v_1}{v_2} = \frac{k\,w}{r}$, and its total cost per year is $2\,R\,k\,w\,v_1 = 2\,R\,k\,\frac{w\,v_2}{r}$ where R is the number of revolutions made by the engine per annum.

To this weight is to be added steam wasted by cylinder condensation, leakage, and by conduction and radiation from engine and boiler. This last quantity varies greatly with kind of engine, speed of piston, and other circumstances more or less

under control of the builder or engineer. It sometimes even amounts to several times as much as the steam actually utilized. It may be allowed for by multiplying the last item by a factor greater than unity.

5. *Theory of the Efficiencies of the Perfect Ideal Steam-Engine.*

When, as is perhaps sometimes allowable, if treating of the best of modern engines, the variation of cylinder condensation with variation of the ratio of expansion may be neglected, the "EQUATION OF IDEAL STEAM-ENGINE EFFICIENCIES," as the writer would call it, may be written:

$$C = \frac{1}{E^{\text{iii}}} = \frac{A\,r\,v_1 + B\,v_1}{2\,R\,W_n} = \frac{A + B\,r^{-1}}{2\,R\left(p_1\dfrac{n r^1 - r^{-n}}{n-1} - p_b\right)}$$

where C is the counter efficiency, and E^{iii} is the ratio of work done to variable costs, and therefore in the sense adopted here, the efficiency. This becomes a minimum, and the best ratio of expansion is obtained when, r being made the independent variable,

$$A\,p_1\frac{n - n\,r^{1-n}}{n-1} - B\,(p_1 r^{-n} - p_b) = 0\,;\; r^{-n} - M\frac{n - n\,r^{1-n}}{n-1} = \frac{p_b}{p_1}$$

Here r has become r_e^{iii}. In these equations A is the total annual variable charge per cubic foot of cylinder on engine account, B is the annual cost of steam per cubic foot *filled* each stroke, and is measured by $2\,R\,w\,k$, when R is the number of revolutions of engine *per annum*, w the weight of a cubic foot of steam at the pressure p_1, and k its cost per pound, including all running expenses, in the boiler-room, and $M = \dfrac{A}{B}$.

More explicitly: since this problem demands minimum cost of a known power and the Ratio of Expansion at Maximum Commercial Efficiency, we have

$$p_1 v_1\frac{n - r^{1-n}}{n-1} - p_b r v_1 = \text{Constant} = W.$$

The variable cost will be, as before,

$$K = A r v_1 + B v_1,$$

which is to be a minimum. But, from the equation of condition, above,

$$v_1 = \frac{W}{p_1 \dfrac{n - r^{1-n}}{n-1} - p_b r}.$$

Thence

$$u = \frac{M + r^{-1}}{nr^{-1} - r^{-n} - \dfrac{p_b}{p_1}(n-1)};$$

and the minimum is found, as above, when $\frac{du}{dr} = 0$; *i. e.*, when

$$r^{-n} - M\frac{n - nr^{1-n}}{n-1} = \frac{p_b}{p_1}.$$

The construction of the equation shows that, under the assumed conditions, this ratio of maximum commercial economy is not dependent on the size of engine; but small engines have a higher value of p_b than large engines; they are usually more subject to cylinder condensation, and have greater back pressure and friction; they therefore require to be worked with somewhat less expansion than large engines.

Thus the solution of the problem determining the ratio of expansion r_e^{iii} at "Maximum Commercial Efficiency," or Efficiency of Capital, fixes that size of engine which, doing the required work, will do it at least cost. The sum of all variable expenses being here made a minimum, the total running expense, which includes all variable charges, also becomes the least possible, and the given work is done at least total annual cost.

To find the ratio of expansion at which a given engine will give the largest amount of work for the dollar, *i. e.*, to determine the "Ratio of Expansion r_e^{iv} at Maximum Commercial Efficiency of a Given Plant," we may use this same general equation. In this case, the size of the engine being fixed, the annual "cost of engine" becomes constant, and we write the equation in precisely the same form as before.

$$C = \frac{1}{E^{iv}} = \frac{A_1 r v_1 + B v_1}{2 R W_n}$$

making the symbol A_1 cover all annual expenses of the engine-room, estimated per cubic foot of cylinder, including all the *con-*

stant charges of attendance in the boiler-room as well, while B only includes costs variable with the steam supply; C thus measures the ratio of total annual expenses of operation to work done. We thus obtain such a ratio of expansion that

$$r^{-n} - N\frac{n - n\,r^{1-n}}{n-1} = \frac{p_b}{p_1}$$

when N is the ratio of the total expenses classed with engine cost to the "cost of full steam," as already taken, and r has become r_e^{iv}.

Again: making A and N equal zero in the general equation, and making p_b the sum of all useless resistances

$$r^{-n} = \frac{p_b}{p_1}$$

and $r = r_e^{ii}$, the ratio of expansion at "Maximum Efficiency of Engine."

Similarly, if p_3 is the back pressure in the steam cylinder

$$r^{-n} = \frac{p_3}{p_1}$$

and we have the ratio of expansion at "maximum efficiency of fluid," $r = r_e^{i}$.

In each case, the expression obtained is derived, it will be noted, by making r the independent variable, and the first is independent of the actual size of the engine. Thus we determine, in each case, that ratio of efficiency which is correct under the assumed conditions for all engines of the class upon which our estimates are based.

We thus are able to *tabulate* the proper size of engine for assumed quantities of work, and the powers at which each engine, once set, will work with maximum efficiency, commercial or other, if the power can be utilized. Finally, comparing costs, it can be determined in any known case just when a change of engine will be financially advisable. But the above simple and beautiful method of treatment cannot be applied where cylinder condensation becomes a serious item; in fact, therefore, it is comparatively valueless for nearly all cases which arise in engineering practice.

A comparison of the quantities of steam demanded to supply an engine thermodynamically "perfect" with the actual quanti-

ties required by even the best engines exhibits so wide a difference that it becomes obvious that the determination of the efficiency of an engine and the solution of the questions involving those of expenditure of heat are not problems in thermo dynamics simply. The mathematical theory of the steam-engine is not yet in so satisfactory a state—and cannot be until the correct theory of this transfer of waste heat can be introduced into it—that the engineer can often use it in everyday office-work with much confidence, unless checked by direct experiment. Even where algebraic analysis is probably capable of giving approximate results, few engineers will attempt to use it. For the last case, however, Rankine's graphical treatment of the problem here studied is conveniently applicable, and by its use the engineer may easily solve such problems by a simple construction on his drawing-board.

6. *Rankine's Diagram of Efficiency.*

In illustration: Suppose an engine, of one cubic foot capacity, in operation, expanding steam adiabatically, its cylinder and piston being perfectly impervious to heat, and having an "adjustable" expansion gear. When following full stroke it uses one cubic foot of steam per stroke, at initial pressure; when "cutting off" at half stroke, one-half cubic foot, and at a cut-off of one-quarter, one-fourth of a foot, is used. The quantity used is always inversely as the ratio of expansion. To determine the best ratio of expansion: Construct a curve, $O\ A$ (Fig. 36), of which the abscissas $O\ X$ are proportional to the amount of steam used, while the ordinates parallel to $O\ Y$ are proportional to the absolute mean pressure for that degree of expansion, and therefore to the "total work" done by the steam so measured off. Drawing a line, $B\ C$, parallel to the base, and at a height proportional to the back pressure in the engine cylinder, the ordinates measured from any point in the curve down to this line will measure the "effective pressure" shown by the indicator, and will be proportional to the "indicated power" of the engine. Again: Drawing a line, $D\ E$, at the height measuring the sum of all useless resistances, the "net" or "dynamometric" power of the engine, as transmitted to the machinery of transmission, is measured by this line. Finally, extending this second line toward the left, and measuring off upon it a distance proportional to the cost of operation, so far as it varies with changes

in plant, and measured on the same scale as is used in laying off the base line in terms of cost of steam, the sum of the two costs, *G F*, measures the total variable expense of obtaining the power, while the height of ordinate *G H*, measured from the last drawn line, is proportional to the amount of power obtained. For any one point, *F*, the straight line *F H*, drawn just

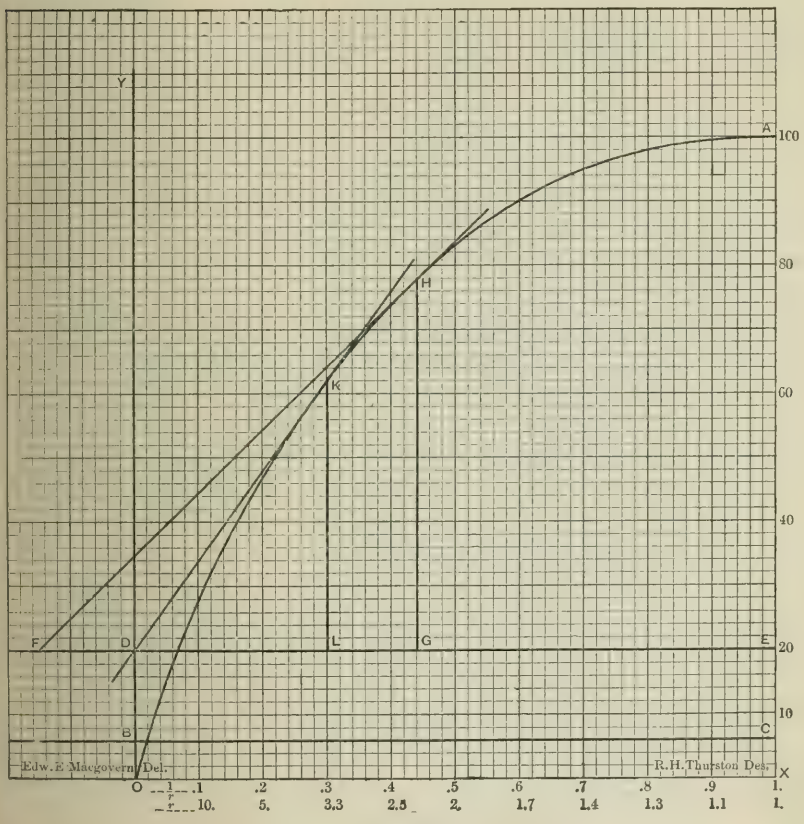


FIG. 36.

tangent to the curve, touches the latter at a point marking the ratio of expansion at maximum commercial economy, or if drawn from the axis *O Y*, as *D K*, identifies the ratio for maximum "efficiency of engine" as that term is technically applied.

This simple construction is correct and exact only when cylinder condensation may be neglected. It has been applied by Rankine to the case of the Cornish Engine, which—because of its effective steam jacketing, singular steam distribution, and

the peculiar rapidity with which the piston, on the "in-door" stroke, jumps from one end of the cylinder to the other—is usually less affected by that most serious of losses, than is almost any other known form of engine. For other forms of engine this construction leads to results that are often, as will be seen presently, widely inaccurate. It has become perfectly obvious that any method to be accurate and reliable must take account of *all* losses of heat of large amount, and must distinguish between efficient and inefficient classes of heat engines.

7. *Theory of Efficiencies of Real Engines.*

The direct process of analytical treatment of this General Problem for Real Engines, as adopted by the writer, is the following: Let it be known what style of engine is to be adopted for any case and what kinds of boilers and attachments are to be used in supplying steam; let the costs of attendance and all other expenses be ascertainable. Then, to adopt Rankine's terms, determine A, the annual variable "cost of engine" of the selected type, per cubic foot of steam cylinder, and B, the annual variable "cost of boiler," per cubic foot of steam cylinder supplied without expansion and without allowance for cylinder condensation or leakage; ascertain all other costs, invariable with change of size of either engine or boiler within the range of the problem, and call their total C.

The "cost of engine" will be $A v_2 = A r v_1$; the "cost of boiler" will be $B v_1$ and the constant charges D. Make $\frac{A}{B} = M$.

The work done per stroke may be called W_n, and work per annum becomes $2 R W_n$.

The ratio of the total of annual variable cost of power to work done by the engine is:

$$u = \frac{A r v_1 + B v_1}{2 R W_n} = \frac{A v_2 + B v_2 r^{-1}}{2 R W_n}$$

which is a minimum when $\frac{M + r^{-1}}{W_n}$ is a minimum.

This value of W_n may be obtained by multiplying the value of W_n for adiabatic expansion, such as would be obtained in a non-conducting cylinder by a factor less than unity variable with the ratio of expansion, as has been shown in the preceding paper,

which shall measure the ratio of actual work done in the metal cylinder to that done in adiabatic expansion. Thus:

Let b represent the proportion of steam present in the working fluid when $r = 1$, as determined by the amount of cylinder condensation; let r^q represent the rate of variation of losses with increase of the ratio of expansion, and let n be the index for the actual expansion line of the mixture, to be determined, if possible, by experiment.

Then we shall have: $W_n = 2\,R\left(b\,p_1 v_2 \frac{n\,r^{-1} - r^{-n}}{n-1} r^q - p_b v_2\right)$.

THE "GENERAL EQUATION OF ALL STEAM-ENGINE EFFICIENCIES," therefore, is

$$C = \frac{1}{E^{iii}} = \frac{A\,v_2 + B\,v_2\,r^{-1}}{2\,R\left(b\,p_1 v_2 \frac{n\,r^{-1} - r^{-n}}{n-1} r^q - p_b v_2\right)} \qquad (A)$$

which becomes a minimum and makes the *Commercial Efficiency* of an engine doing the required work a maximum when, to obtain r_e^{iii}, we have made

$$r^q + \frac{q}{M(q-1)} r^{q-1} - \frac{q-n}{n(q-1)} r^{q-n+1} - \frac{q-n+1}{Mn(q-1)} r^{q-n} = \frac{n-1}{Mnb(q-1)} \frac{p_b}{p_1} \qquad (B)$$

When the ratio of expansion, r_e^{iv}, at "*Maximum Efficiency of a Fixed Plant*" is required, $A^v{}_2$ is constant, and we may make $\frac{A + \frac{D}{v_2}}{B} = N$ and the equation of *Efficiency of Plant*

$$C = \frac{1}{E^{iv}} = \frac{N + r^{-1}}{2B^{-1}R\left(bp_1v_2 \frac{nr^{-1} - r^{-n}}{n-1} r^q - p_1v_2\right)} \qquad (C)$$

gives, similarly, for r^{iv} and a maximum,

$$r^q + \frac{q}{N(q-1)} r^{q-1} - \frac{q-n}{n(q-1)} r^{q-n+1} - \frac{q-n+1}{Nn(q-1)} r^{q-n} = \frac{n-1}{Nnb(q-1)} \frac{p_b}{p_1} \qquad (D)$$

To obtain r_e^{ii} for *Maximum Efficiency of Engine*, we make $N = 0$ and have

$$r^{q-1} - \frac{q-n+1}{nq} r^{q-n} = \frac{n-1}{nbp} \frac{p_b}{p_1} \tag{E}$$

and to obtain *Maximum Efficiency of Fluid*, p_b becomes p_3 and

$$r^{q-1} - \frac{q-n+1}{nq} r^{q-n} = \frac{n-1}{nbq} \frac{p_3}{p_1} \tag{F}$$

in which r_e^{i} satisfies the equation.

When $b = 1$ and $q = 0$, we have the *ideal* case considered in § 5, and the equation (B) for r_e^{iii} becomes, as before, for the perfect engine:

$$r^{-n} = M \frac{n - n^{1-n}}{n-1} = \frac{p_b}{p_1} \tag{G}$$

for Maximum Commercial Efficiency; and we again obtain for Maximum Economy of a Given Plant, for r_e^{iv},

$$r^{-n} - N \frac{n - nr^{1-n}}{n-1} = \frac{p_b}{p_1} \tag{H}$$

For Maximum Efficiency of Engine, we again get a value of r_e^{ii}, such that

$$r^{-n} = \frac{p_b}{p_1} \tag{I}$$

and finally for Maximum Efficiency of Fluid we find a value of r_e^{i}, such that

$$r^{-n} = \frac{p_3}{p_1} \tag{J}$$

precisely as already stated in § 5.

The quantities of steam and of fuel used per hour and per horse-power in the non-conducting cylinder with and without expansion, and in the metal cylinder, with and without expansion, are as

$$1 : \frac{p_1}{p_m r} \text{ and } \frac{1}{br^{-q}} : \frac{p_1}{bp_m r^{q+1}}.$$

In general, where the Equation of the Curve of Efficiency is given, we shall have at Maximum Efficiency of Fluid

$$\frac{dy}{dx} = \frac{p_m - p_3}{p_1} b r^{q+1};$$

at Maximum Efficiency of Engine,

$$\frac{dy}{dx} = \frac{p_m - p_b}{p_1} b r^{q+1};$$

at Maximum Efficiency of Plant,

$$\frac{dy}{dx} = \frac{p_m - p_b}{1 + N b r^{q+1}} \cdot \frac{b r^{q+1}}{p_1},$$

and at Maximum Efficiency of Capital,

$$\frac{dy}{dx} = \frac{p_m - p_b}{1 + M b r^{q+1}} \cdot \frac{b r^{q+1}}{p_1};$$

for cases met with in practice ; while the purely thermodynamic treatment gives

$$\frac{dy}{dx} = \frac{p_m - p_3}{p_1} r ; \frac{dy}{dx} = \frac{p_m - p_b}{p_1} r ;$$
$$\frac{dy}{dx} = \frac{(p_m - p_b) r}{p_1 (1 + Nr)} ; \frac{dy}{dx} = \frac{(p_m - p_p) r}{p_1 (1 + Mr)}$$

for these several cases for the perfect engine.

For the *ideal* case, x and y being the co-ordinates, the equation of the Curve of Efficiency gives

$$\frac{y}{x} = \frac{p_m}{p_1} \div \frac{1}{r} = \frac{n - r^{1-n}}{n - 1}.$$

For the real engine,

$$\frac{y}{x} = \frac{p_m}{p_1} \div \frac{1}{b r^{q-1}} = b^2 r^{2q} \frac{n - r^{1-n}}{n - 1}.$$

It will be remembered that ordinates represent the work done by the quantities of steam measured by the corresponding abscissas.

The constants in these formulas should be carefully determined, if possible, by experiment on the class of engine to be

designed; but, in the absence of better data, are taken by the writer, when designed, as follows, for good practice:

	b.	q.	n.
I. Cylinders jacketed, steam superheated at boiler,	0.90	0.00	1.06
II. Cylinders jacketed, steam saturated, but dry at boiler,	0.88	—0.20	1.06
III. Cylinders unjacketed, steam saturated, but dry at boiler,	0.88	—0.25	0.99
IV. Cylinders unjacketed, steam wet,	0.85	—0.30	0.98

n is the exponent of the probable actual curve.

Case I. is illustrated by the best work yet done by Corliss, Leavitt and Cowper. The value of b is obtained by comparing the actual results of test with the figures for the perfect engine to determine the waste; that of n is obtained by consideration of the fact that in these engines, when effectively jacketed, the steam is retained just dry and saturated during the stroke, and q is taken to be 0, since the rate of transfer of heat to exhaust is nearly constant for such engines so far as known, and is of minimum amount. The values for Case II. are obtained by examining scattered records of somewhat less efficient engines. The values of b and q for Case III. are obtained by studying the performance of good unjacketed engines; while those for the last, Case IV., came originally from the results of test of the United States steamer *Michigan*, with an allowance of ten per cent. for the unrecorded waste concealed by re-evaporation.

8. *Curve of Efficiency for Real Engines.*

The correct curve for the diagram, as has been seen, is neither that due to diabatic nor that given by isothermal expansion, nor is it any known intermediate curve; it has not as yet been expressed by any exact equation.* It is never the curve of mean pressures, obtained on the assumption of any yet classified method of expansion, and rarely approximates to either of the ideal engine curves. It is very variable in location, in form, and in dimensions, and, as yet, can only be determined by experiment.

In the diagram above given, it is thus evident, the quantities

$-br_c$,

* An inspection of these curves would indicate that the equation, $y = ae$ may be more exact than the more manageable forms used by the writer. The general character of these curves was first pointed out by him in debate at the meeting of the Am. Soc. Mech. Engrs., May, 1881.

of steam laid down in arithmetical progression on the base line cannot now correspond with the ratios of expansion there taken; since in actual engines those values are not in exact, or in constant, inverse proportion. The quantity of steam drawn from the boiler is not measured by the volume of cylinder open to steam up to the point of cut-off; nor is the mean pressure obtained with any given weight of steam drawn from the boiler at each stroke, even approximately, equal to that given by adiabatic expansion in a non-conducting cylinder. Both these variations operate to depress and flatten the Curve of Efficiency on the diagram, and thus often to reduce the ratio of economical expansion far below that predicted when the former and impossible conditions were assumed. The vertical scale of pressures and the horizontal scale of ratios of expansion have become altered in relative magnitude, and the latter becomes for usual cases a variable scale.

To obtain a solution of the actual problem as presented daily to the designing engineer, a new method of procedure must be adopted. The writer proposes the following, as simple in principle, easy of application, and especially as giving, from the use of experimentally derived data, results which may be received with confidence and used for any engine falling into the class of typical cases studied.

9. *Thurston's Diagram and Curve of Efficiency.*

It has become evident that the best ratio of expansion or proper "point of cut-off" for any actual case is determined, not by the percentage of loss sustained at that point simply, or by the cylinder condensation there taking place, but by the *method of variation* of such loss, not only at that point, but all along the curve of efficiency and at other ratios of expansion; for, in the metallic cylinder, the proportion of the water present in the working fluid is constantly varying with change of volume, and the loss of pressure and of work is constantly and proportionally varying, producing a curve of efficiency differing greatly in character, form, and location from that given by a non-conducting cylinder.

This "Curve of Efficiency," as discovered by the writer, and first described in the paper already referred to, is, therefore, a curve of peculiar character and essentially different from the line of mean pressures used by Rankine. It is obtained thus:

Assume for the unit of measure so much steam as is drawn from the boiler at one stroke of piston, without expansion or condensation; draw OX (Fig. 37) and divide it as unity of volume or of weight into a scale of equal fractional parts which are to be laid down on both sides of O. Erect at X a perpendicular, XBA, and divide it into any convenient number, say 100, of equal parts. Were there no condensation, the fluid being worked

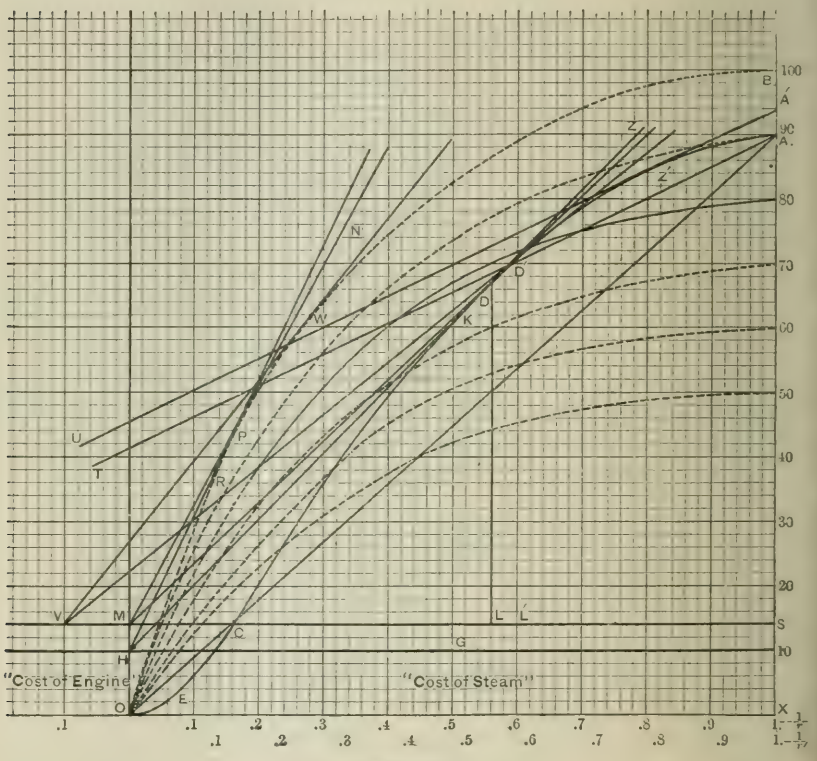


FIG. 37.

in a vessel of non-conducting material, instead of an iron steam-cylinder, the mean pressure at full stroke and the work done per cubic foot or per pound of boiler steam would be measured by XB, and the curve of mean total pressure or of steam used per "total" horse-power per hour would be OWB.

Condensation reduces the work at full stroke, and it is actually measured by XA. Were the condensation in constant proportion for all values of the real ratio of expansion, the ordinates of the true curve would be proportional to those of OB, and the

values of $\frac{1}{r}$ would remain proportional to the expenditure of steam as in adiabatic expansion. But the amount of condensation usually increases, and often very rapidly, with increasing expansion; and at one-half, one-quarter, or one-eighth cut-off, more, and sometimes much more, than one-half, one-quarter, or one-eighth as much steam is used as at full stroke. The scale of ratios, $\frac{1}{r}$, is thus not only shifted but is made a scale of unequal parts, of which the successive values must be located by determining the amount of steam used at each point of cut-off, and placing the value $\frac{1}{r}$ opposite the value of the corresponding amount of steam expended, as has been done in Fig. 37, along the scale $\frac{1}{r}$.

If, as is sometimes nearly true, the losses by condensation and leakage, or both, are so great as to annul the benefit derived from expansion, the curve flattens down to a straight line, OA. In every engine a point is reached by increasing r at which the amount of steam used per hour per total horse-power is as great as at full stroke; in every case, therefore, the true curve crosses the line OA, as at C. In every unjacketed, and perhaps in jacketed engines, a point is reached before the curve terminates at O, at which the ratio of expansion becomes so large, the expenditure of steam so small and losses so great, that the curve falls nearly to the axis OX; thus, instead of crossing OX, it has a point of contrary flexure between C and O. The line $OECDA$ is thus representative of the class of mean pressure or efficiency curves given by actual engines. Could the variation of expenditure of heat be exactly expressed by an algebraic equation, this equation would be that of the line $ACEO$, and the problem would be capable of exact solution by algebraic methods.

Another, and, in some respects, more readily understood, although less exact, method of constructing the curve of efficiency is to make the base scale a uniform scale *both* of steam consumption and of cut-off, as for adiabatic expansion, and then to make the ordinate, at any point, proportional to the quantity of work done at the given point of cut-off by the quantity of steam there measured, as was done in the preceding paper.

10. *Solution of Problems of Efficiency for Actual Engines.*

Draw HG at a height above OX equal to the back pressure, p_3; then the tangent line HK identifies a point K, which gives the ratio of expansion at *maximum efficiency of fluid*—since the ordinate GK measures the work done by the steam drawn from the boiler—and the ratio $\frac{GK}{HG}$ becomes a maximum at K. Drawing ML to represent the pressure demanded to overcome all useless resistance, $p_b = p_3 + f_1$, a similar construction identifies D as the point corresponding to the ratio of expansion at *maximum efficiency of engine*. Finally, extending this line to V and making VM proportional to cost of all variable running expenses, stated in terms of cost of steam per cubic foot of cylinder, $VM = \frac{A'}{B} = M$, when working at full stroke, the tangent line VZ meets the curve at a point near D', which gives the ratio of expansion at *maximum commercial efficiency*. Comparing these values of r with those given by the tangents, HR, MP, VW, drawn to the curve OB, for dry saturated steam, expanded adiabatically, it is seen that the best ratio of expansion must be, in each actual example, less than in the hypothetical case, and may even become unity for each kind of *efficiency*, with very slow piston speed, where, were no loss of heat to occur in the manner here considered, considerable expansion would be desirable. These differences all become greater as the back pressures and current expenditures become less.

Making the value of VM a measure of the total current expenses, including the constant as well as variable items of cost of attendance, as those of rent, insurance, etc., which do not depend on size of engine, $VM = \frac{A'}{B} = N$, a value of r will be obtained which is that real ratio of expansion at which *maximum work is done for a given expenditure*, per hour or per annum, on a plant actually established. This problem is less frequently presented to the engineer than those already given, and is not the problem of maximum commercial efficiency; since this ratio and the corresponding power of engine being determined, it will be found on solving for maximum commercial efficiency that another proportion of engine with higher ratio of expansion will supply the power now demanded, at still lower cost. To this

latter engine the last problem again applies. The practical conclusion to be drawn from the solution of the interminable succession of problems of this last character, which thus follow the first, is that the largest amount of power possible should be intrusted to a single engineer or crew of attendants, and placed under one roof, etc.

Finally, the last of the problems enumerated at the beginning of this paper may be solved with equal ease.

To ascertain just what ratio of expansion and what amount of work, as a maximum, can be profitably obtained from an established plant, calculate the net power obtainable from the engine without expansion, and the market value, or otherwise real value to the proprietor, of that power, and estimate, also, the cost of fuel and all items of cost variable therewith. Divide the price of power by this cost. Then lay off, on the base line appropriate to the given engine, the distance SV, produced, equal to the quotient, taking the distance MS as unity, and from the extremity of this base line draw a straight line TA, to the point A, at the altitude AS equal to the measure of the net power just calculated. Finally, draw a line UA, parallel to this hypothenuse of the triangle so described, and tangent, as at Z', to the curve of efficiency. The point of tangency Z' will identify the *minimum profitable ratio of expansion* and determine the maximum amount of work obtainable from this engine with profit. For, at this point of tangency the ratio of total cost of power to the price obtainable for it, or to its actual value, is that already given as the greatest permitting a fair profit, while the ratio of expansion so determined is that giving that power at that rate of cost.

The value of the *Ratio of Expansion at Maximum Profitable Power* is evidently, in all actual examples, less, and the work done is greater, than in either of the preceding cases, and *is dependent upon the market value of that power.*

In all cases, the ratio of expansion calculated is the real ratio; the apparent ratio is decreased by clearance, and increased, often considerably, by the wiredrawing which occurs just before the valve is seated. It is evident that loss of steam by leakage modifies the curve of efficiency in the same general way as loss of heat by cylinder condensation.

Section 2. Applications and Deductions.

11. *Method of Construction of the Diagram of Efficiencies.*

By the application of this method, as proposed by the writer, we may thus determine, from the results of experiment, a set of data and a graphical representation of those results which may serve as a standard for the class to which the engine examined belongs.

It is further evident that, the ratio of expansion at maximum efficiency being determined by experiment and with precision by this graphical method, it becomes easy to ascertain with exactness the value of the ratio of expansion at maximum commercial economy.

The base line, VL, for maximum efficiency of engine being fixed, the position of the point V on that line is readily obtained, and thus the line VZ becomes known, and the ratio of expansion at maximum commercial economy is determined. Similarly, by extending the line VL until it becomes proportional to the sum of all costs, constant and variable, the ratio of expansion giving maximum work per dollar expended with the given engine, may, if desired, be found.

The accompanying plate (Fig. 38) represents a series of real Curves of Efficiency, several of which are given by working engines. Such curves are here, for the first time, presented.

The straight line $A_1 A$, for the case in which $[n = (-1)]$ is the line of Constant Efficiency obtained in an assumed case of no gain and no variation of efficiency with increasing expansion from $r = o$ to $r = \infty$.

The curve marked G, and dotted, is the standard Curve of Efficiency for adiabatic expansion of steam containing initially ten per cent. water ($n = 1.125$).

The line F is the Curve of Mean Pressure or of Efficiency for steam initially dry ($n = 1.135$).

The other curves are all obtained by reference to experiments on various classes of engines. B is the Curve of Efficiency for the common marine, unjacketed, single cylinder, condensing engine; C is the Curve of Efficiency for the same engine using superheated steam; D is that of a "compound" jacketed, condensing, marine engine; E applies almost exactly to both non-condensing engines and compound engines of the best classes,

and the curve F is practically correct for the last-named class of engines when the steam is kept thoroughly dry by effective superheating and reheating in a receiver.

Curve B is thus obtained:

Collating Isherwood's with other experiments made for the United States Navy Department, which are almost the only valuable experiments for our present purpose ever made on this class of engine as used on our river steamboats and in the Naval Service,* we find the following relative measures of steam consumption at various ratios of expansion, and of work done by it.

Cut-off $\frac{1}{r}$ (real), . . .	.1	.3	.5	.7	.9	1.00
" $\frac{1}{r'}$ (apparent), . .	.05	.25	.47	.68	.89	1.00
Relative weights of steam .	.16	.41	.60	.76	.92	1.00
" " total work " done,	.21	.56	.82	.97	1.00	1.00

The base line, B, for this case, in which $\frac{p_b}{p_1} = \frac{1}{8}$, is drawn on the plate, and on this line are a set of values of $\frac{1}{r}$ corresponding to the relative weights of steam as laid down on the bottom scale, .10 above .16, .30 above .41, etc., etc., and the ordinates erected at these points are made proportional to the total work done at those ratios of expansion; and, thus carefully laying down these points, the line B_1 B is constructed as the Curve of Efficiency for the engine, of which those of the United States steamers "Eutaw," "Michigan," and all "American River Steamboat Engines" are representatives.

In a similar manner, by collating the data obtained by the trial of the "Georgiana's" engine, using superheated steam, with the experiments of Hirn showing a reduction of exhaust waste by superheating, we obtain the Curve of Efficiency C_1 C, and the Base Scale accompanying it.

A set of experiments on the "Bache" gives the line D_1 D, and the curve E_1 E is found, by trial, to meet cases of good work with non-condensing engines, unjacketed, but worked at high piston-speed, and of some of the very best results obtained with compound engines of the most successful types.

* "Researches in Engineering," vol. ii.; table, p. xxxiv.

Curve F seems to meet those cases in which superheating has been so efficient as nearly to prevent all condensation, and the line corresponds closely with the adiabatic for steam, dry initially, and only condensing so much as is due to the performance of work.

The location of these lines, as well as their form, is evidently variable with every change affecting efficiency.

The writer has been unable to find sufficiently complete series of experiments reported, to construct these last curves as exactly and satisfactorily as the first, and has been compelled to work from scattered and comparatively incomplete data. The results, so far as comparable with practice, seem to indicate sufficient accuracy to have been obtained for such illustration as is here necessary; but extended experiments on the more modern engine —like those experiments for which we are indebted to Isherwood, on earlier forms—are much needed. Even curve B is not as far removed as it should be from the adiabatic curve, since it is constructed on the assumption that re-evaporation could be neglected in the case studied, an inexact assumption, but one made necessary by the absence of data relating to condensation at the point of cut-off. The writer would be inclined to increase the proportion of loss taken from the record by at least an additional 10 per cent., making the total, probably, equal to

$$h_c = 0.2 \sqrt{r} \text{ nearly.}$$

To obtain an exact solution of these problems, the quantity of steam present in the cylinder *at the point of cut-off* must be precisely measured and compared with the quantity sent to the engine from the boiler. This absolutely essential comparison has been very rarely made by engineers conducting trials of steam-engines.*

* In fact, the only nearly complete sets of essential data given on any engines are those published in reports of United States Naval Engineers and by Hirn. Investigators have not yet learned the importance of ascertaining, in every engine trial, the weight of water passing through the engine, and of comparing it with the weight of steam present *at each point* of the stroke as measured by the indicator. Where experiments, otherwise valuable, have been made, it has rarely occurred that any one set of conditions has been preserved constant, while observing other variables, so as to secure any useful data for investigations like the present. Professor Cotterill's treatment should be applied in every case to secure a full and satisfactorily valuable set of data.

12. *Mode of Application of the Method and Use of the Diagram.*

Comparing curves F and G, representing the case of steam expanding in a non-conducting cylinder, *i. e.*, adiabatically, with the other curves, obtained for expansion in real engines, it is seen, at a glance, that the more perfectly exhaust-waste by cylinder condensation is guarded against, the more closely does the actual engine approach to the perfect engine in its utilization of steam, and the less effective the provision against such loss the more widely does the Curve of Efficiency depart both in location and form from the ideal curve, finally approximating to the straight line of Constant Efficiency $A_1 A$. While the best engines approach comparatively near the curve of maximum possible efficiency, the great majority of condensing engines in use are of the class represented by that giving Curve B, which latter is, however, by no means a case of remarkably low efficiency. In many cases the curve will be found to fall within the line B.

Selecting one of these curves, as B, or C, we may solve either or all of the problems already defined by merely applying a straight-edge to the diagram. For B we have $p = 40$; $p_b = 5$; $\frac{p_b}{p_i} = \frac{1}{8} = 0.25$. To determine the Ratio of Expansion at Maximum Efficiency, draw the base-line at the altitude 0.125, and from its junction with the ordinate at the zero point, draw the line HI tangent to the curve; it touches the curve at I, and the corresponding ratio of expansion on the base-line beneath is a trifle less than $\frac{1}{r} = 0.4$; $r = 2.5$ nearly—a result confirmed by reference to the original data.

Next, ascertain the hourly or annual cost of supplying the engine with steam worked without expansion or cylinder condensation, including all items of expense variable with the quantity of steam used, and determine the *variable* part of all running expenses in the engine-room, including interest, insurance, rent, cost of oil, and so much of the wages of the attendants as is properly taken as variable with the size of the engine. Suppose, as in a case taken by the writer, that the latter is found to be two per cent. of the former, $M = 0.02$.

From the point T, at the ordinate 0.02, on the left of the H, draw the tangent to the curve as TL on the curve B; its point

of tangency identifies the best ratio of expansion for commercial efficiency.

Similarly compare the "cost of full steam" with the sum of all other running expenses chargeable to the plant; if the ratio is $N = .04$, draw the tangent line WL from the ordinate .04 and thus find that ratio of expansion which will give most work for the money expended on a plant already installed. The lines PQ, RV and SU thus determine these three ratios for the curve F, of a well-constructed non-condensing engine, using perfectly dry steam and with a ratio $\frac{p_b}{p_1} = 0.20$. The line NM determines the ratio of expansion at maximum efficiency for the case D, a compound engine doing good work with $\frac{p_b}{p_1} = 0.05$.

13. *Estimation of Expenses.*

The following example illustrates, in detail, the calculation of M and N:

Rated power of given engine and boiler,	500 H.P.
Working time, per annum,	3,000 hrs.

(*A.*) *Cost of Engine* (*variable with size of engine*).

Cost of engine,	$10,000
Annual interest at 6 per cent.,	$600
" cost of repairs and depreciation, 4 per cent.,	400
" materials used,	50
Total annual cost,	$1,050

(*B.*) *Cost of Boiler* (*variable with demanded boiler-power*).

Cost of boiler: actual, $12,000; for "full steam,"	$24,000
Interest on cost, using steam without expansion, at 6 per cent.	$1,440
Repairs and depreciation, at 15 per cent.,	3,600
Minor expenses per annum,	200
Total annual maximum cost,	$5,240

(*C.*) *Fuel Account* (*variable with size of boiler*).

Coal, per year at the rated power,	2,000 T
" " with no expansion,	4,000 T
Cost of fuel at "full steam," at $5 per T,	$20,000
" " transportation and storage at 50 c.,	2,000
Total maximum per year,	$22,000

(*D.*) *Attendance* (*wholly or partly constant or variable*).

(*a*) Engine-driver's (engineer's) pay per year, . .	$1,000
(*b*) Fireman's (stoker's) pay, per year ("full steam"), .	1,200
	$2,200

(*E.*) *Incidentals* (*constant as a rule*).

Rents, taxes, insurance, etc. per annum, . . .	$1,000

Studying the statement of costs, the mechanical engineer decides in each case, and for each problem presented, how the items should be grouped. For the case of a stationary steam-engine such as is here presented, he would find:

$$M = \frac{(A)}{(B) + (C)} = 0.035, \text{ nearly},$$

if the costs (D_a), (D_b) are not variable within the probable range of variation; or

$$M = \frac{(A)}{(B) + (C) + (D_b)} = 0.03, \text{ nearly},$$

if the cost of fire-room labor is variable with quantity of steam demanded. Then

$$N = \frac{(A) + (D) + (E)}{(B) + (C)} = 0.15, \text{ nearly},$$

for the first case, and

$$N = \frac{(A) + (D_a) + (E)}{(B) + (C) + (D_b)} = 0.10, \text{ nearly},$$

for the second case. In marine steam engineering, storage becomes an important matter, in items (A) and (D) and (B), as well as very important in (C) and (E), since every cubic foot occupied by machinery, fuel, or attendants displaces a cubic foot of paying loading. With very large powers, the items (D) both become to a certain extent variable, the one (D_a) with magnitude of the whole plant, the other (D_b) with quantity of fuel burned. Correctness in making up the bill of costs will be found to be absolutely essential.

14. *Statement of Results.*

Laying out these curves on a conveniently large scale and proceeding as just indicated, the writer obtained the results

exhibited in Table I, here given. Cases I to VI, inclusive, are obtained from Curve *E;* VII to XII from Curve *B;* XIII to XVIII from *E,* and XIX to XXIV from the best Curve of Efficiency, on the plate, Curve *F.*

The Ratio of Expansion at Maximum Efficiency of Fluid will be found in column r_e^{i}, that at Maximum Efficiency of Engine under r_e^{ii}, and the best Ratio of Expansion for Commercial Efficiency, or for Maximum Efficiency of Capital, is given under r_e^{iii}. *M, N,* are the ratios of cost. Comparing the first and especially the second set with the last, the enormous variation due to cylinder condensation is readily appreciated. Even the last case is far from the efficiency of the perfect engine.

The ratios of expansion for superheated steam in the unjacketed cylinder are obtainable from Curve *C.*

Table I.

Ratios of Expansion at Maximum Efficiency of Fluid of Engine and of Capital.

Single Cylinders.

Absolute Initial Pressures.			Case No.	Class I. Non-Condensing. High Speed.						Case No.	Class II. Condensing, Moderate Speed.					
P	P_m	Atmospheres.		p_s	p_b	M	$\frac{p_1}{p_b}$	r_e^{i}	r_e^{ii}	r_e^{iii}		p_s	p_b	M	$\frac{p_1}{p_b}$	r_e^{i}	r_e^{ii}	r_e^{iii}
40	2.8	$2\frac{2}{3}$	I	18	20	.02	2	2	2	2	VII	3	5	.04	8	$2\frac{1}{2}$	$2\frac{1}{4}$	2
60	4 2	4	II	18	20	.02	3	3	3	$2\frac{3}{4}$	VIII	3	5	.04	12	$3\frac{1}{2}$	$3\frac{1}{4}$	3
80	5.6	$5\frac{1}{3}$	III	18	20	.02	4	4	$3\frac{3}{4}$	$3\frac{1}{4}$	IX	3	5	.04	16	$4\frac{1}{4}$	4	$3\frac{3}{4}$
100	7.0	$6\frac{2}{3}$	IV	18	20	.02	5	5	$4\frac{1}{2}$	$3\frac{1}{2}$	X	3	5	.04	20	$4\frac{3}{4}$	$4\frac{1}{2}$	4
120	8.4	8	V	18	20	.02	6	6	$5\frac{1}{2}$	4	XI	3	5	.04	24	$5\frac{1}{2}$	5	$4\frac{1}{2}$
150	10.5	10	VI	18	20	.02	$7\frac{1}{2}$	7	6	$4\frac{1}{2}$	XII	3	5	.04	30	6	$5\frac{1}{4}$	5

COMPOUND, CONDENSING, JACKETED.

Absolute Initial Pressures.			Case No.	Class III. Saturated Steam.							Case No.	Class IV. Superheated Steam.						
p	p_m	Atmospheres.		p_3	p_b	M	$\frac{p_1}{p_b}$	r_e^{I}	r_e^{II}	r_e^{III}		p_3	p_b	M	$\frac{p_1}{p_b}$	r_e^{I}	r_e^{II}	r_e^{III}
40	2.8	2.	XIII	3	5½	.04	7	6	5	3	XIX	2½	5	.05	8	8	6	5
60	4.2	4	XIV	3	5½	.04	11	8	7	4½	XX	2½	5	.05	12	11	8	6
80	5.6	5⅓	XV	3	5½	.04	14	9	8	6	XXI	3	5½	.05	14	13	10	7
100	7.0	6⅔	XVI	3	6	.04	17	10	9	7	XXII	3	5½	.05	18	16	12	8
120	8.4	8	XVII	3	6	.04	20	11	10	8	XXIII	3	5½	.05	22	20	15	9
150	10.5	10	XVIII	3	6	.04	25	13	10	9	XXIV	3	6	.05	27	25	17	10

[p = Initial pressure measured from perfect vacuum; p_3 = Back Pressure in cylinder; p_b = same, including friction; M = Ratio of variable part of cost of engine to variable part of cost of steam, when $r = 1$, no cylinder condensation occurring.

r_e^{I}, r_e^{II}, r_e^{III} = Ratios of Expansion of Maximum Efficiency of Fluid, of Engine, and of Capital invested to obtain a Given Amount of Power with best engines of each class.]

The values here presented for the several cases are not to be taken by the engineer as exact for other examples. They are given as representative cases, and the engineer designing new engines should, whenever possible, construct his own diagram and make his own solution of the problem before him.

Further investigation will, undoubtedly, sooner or later, establish the Curves of Efficiency for those classes of engine and for those special cases for which the engineer can to-day only obtain them approximately. Meantime, the plate exhibits a range of variation of curve which extends completely across the field of every-day practice, and an experienced engineer can readily trust his judgment in the interpolation of the curve of efficiency for any special case arising in his own practice. For example: Cases of best practice in which the engine is worked at higher speed, and with a warmer condenser, and having less friction, will give a curve for the class from which *B* was obtained, which will fall between *B* and *C*.

The values given of $\frac{p_1}{p_b}$ are interesting in comparison with the values of r_e, as exhibiting this enormous difference between the best ratio of expansion in actual work and the ratio giving maximum efficiency in the ideal case, and also as strikingly presenting to the mind how far we are still, in actual practice, from even an approximation to the ideal condition exhibited in the perfect engine.

TABLE II.

Ratios of Expansion giving Maximum Work at Minimum Cost for a Given Plant of Known Proportions.

	Class I.						Class II.					
Cases	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII.
N	.04	.04	.04	.04	.04	.04	.10	.10	.10	.10	.10	.10
r_e^{iv}	$1\frac{1}{2}$	$2\frac{1}{2}$	$2\frac{3}{4}$	$3\frac{1}{4}$	$3\frac{1}{2}$	4	$1\frac{3}{4}$	$2\frac{1}{2}$	3	$3\frac{1}{4}$	$3\frac{1}{2}$	4

	Class III.						Class IV.					
Cases	XIII.	XIV.	XV.	XVI.	XVII.	XVIII.	XIX.	XX.	XXI.	XXII.	XXIII.	XXIV.
N	.10	.10	.10	.10	.10	.10	.12	.12	.12	.12	.12	.12
r_e^{iv}	$2\frac{1}{2}$	$3\frac{1}{2}$	$4\frac{1}{4}$	$4\frac{1}{2}$	$4\frac{1}{2}$	$4\frac{3}{4}$	4	$4\frac{1}{2}$	$4\frac{3}{4}$	5	5	$5\frac{1}{4}$

Table II gives values, similarly obtained for the cases taken, of that ratio of expansion which gives a maximum quantity of work for a dollar with a fixed proportion of plant. These values are seen to be very much smaller than the ratios for maximum commercial efficiency, and, although they may give more work for a dollar than the higher ratios just determined, they do not give maximum efficiency of capital. For :

Assume the engine working at this newly adjusted ratio for the now given power, still more work will be given for the dollar if the value of r be increased by replacing the given engine by a larger one, in many cases, or in any case by speeding up the engine or otherwise doing the larger amount of work with the higher ratio of expansion. The writer has sometimes accom-

plished this latter result by both speeding up the engine and carrying higher steam,* with an automatic adjustment of expansion. The real limit to this increase of work done by the given engine is determined by quite other considerations than those above noted. It is determined by the money value of the power obtained, and this increase of power finds a limit, as has been seen, only when either the limit of safety in working engine or boiler is reached, or when the money made by the use of additional power is insufficient to pay a fair profit on the additional expense incurred, which latter limit may be obtained at a value of r either equal to or less than r_e^{iv}.

15. *Relation of Costs and Profits.*

Table III exhibits the effect of variation of actual value of the power in determining the maximum amount profitably obtainable from any engine.

For example: Suppose the cost of a horse-power to be, as is frequently the case, about equal to the cost of fuel (in the furnace) producing that power without expansion; then calling this value P_m and this cost P_c, the base line of the diagram will be extended until it measures $\left(\frac{P_m}{P_c} = 1 = N^1\right)$ twice the length of OX, and the angle made by the line from its extremity to A, Fig. 2, makes an angle $\theta = 45^\circ$ with OX. On the large-scale drawing, set the triangle against the edge of the T-square, and adjust it to the line here given; find, by shifting it along the blade, that point on the selected curve of efficiency at which a parallel tangent can be drawn, and then the ratio of expansion, r^v answering to this case, is found.

If an engine, IV of Class I, is selected, it is found to be $r^v = 2\frac{1}{2}$; if No. VII of Class II, $r^v = 2$, etc., etc., as in Table III.

It is particularly interesting and instructive to observe how the importance of cylinder condensation, in its influence on the best ratio of expansion, diminishes with increasing expansion, and that, finally, the most economical and the least efficient give nearly identical figures when the point of cut-off approaches half stroke.

* A favorite occupation of the writer, when engaged in this branch of professional work, was that of designing new and larger steam cylinders for old engines, to meet this case.

Table III.

Effect of Variation of Ratio to Market Value to Cost of Power. Maximum Limiting Values of r^v.

		N'	0.40	0.50	0.60	0.70	0.80	1.00
Class	No.	IV	...	...	...	...	3	2½
" II	"	VII	...	...	...	...	...	2
" II	"	X	...	...	...	...	...	2
" III	"	XV	...	7	5	4	3	2½
" III	"	XVII	...	7	5	4	3	2½
" IV	"	XXI	9	7	6	4	3	2½
" IV	"	XXIV	10	7	6	4	3	2½
θ			22°	27°	31°	35°	39°	45°

Taking the cost of fuel, *in the furnace*, for the engine working without expansion, at $50 per annum per horse-power, the above table gives the ratio of expansion below which a loss will accrue when the cash value of the horse-power is 20, 25, 30, 35, 40 and 50 dollars; at these ratios of expansion, all that is received for power above these sums is profit.

For other costs, the prices obtained must be correspondingly varied to secure a profit.

16. *Profits at any Fixed Expansion.*

Other problems, the converse of the last, may be solved by this construction: "What is the maximum price which can be paid for power without loss at any *given best ratio of expansion?*" "What profit is obtainable at lower cost?" "What total cost makes any given ratio the most economical ratio of expansion?"

To solve these problems, draw an ordinate to the line of mean pressures, or the curve of efficiency, at the assumed ratio of expansion; the abscissa measures the cost in terms of full steam of the power measured by the ordinate, above which loss will accrue, when $M = 0$. The difference between the total cost and the market value measures the profit obtainable if the power is sold at the higher price of the two figures.

Table IV exhibits the variation of the relative maximum allowable cost of power, with variation of the ratio of expansion, actual cost of expenses, variable with fuel without expansion, being taken as unity.

TABLE IV.

Maximum Limit of Relative Allowable Cost. Most Economical Ratio of Expansion assumed as r. Cost of Full Steam, Unity. M or $N = 0.1$.

			r	1	2	3	4	5	6	8	10
Class	1	No.	IV	1.1	.80	.75	.75	.85	.85	...	...
"	II	"	VII	1.1	.80	.85	1.1	...	...	...	...
"	II	"	X	1.1	.75	.80	.95	...	...	...	...
"	III	"	XV	1.1	.75	.70	.70	.75	.80	.90	1.1
"	III	"	XVII	1.1	.75	.70	.70	.70	.70	.75	.90
"	IV	"	XXI	1.1	.75	.70	.90	.65	.70	.75	.90
"	IV	"	XXIV	1.1	.75	.70	.65	.65	.55	.55	.65

17. *Cost of Engine as Affecting the Best Ratio of Expansion.*

The effect of variation in cost of engine now becomes of interest, and indeed a matter of real importance to the designer. Studying cases arising in practice, he will probably find the value of M or N to fall between .02 and .15, as in those selected above, but it will probably rarely, if ever, exceed 0.20.

The curve being established correctly for any given engine, it becomes the easiest possible matter to determine the effect of variation of this ratio. Table IV (A) gives such results as seem most instructive, from the cases here studied.

TABLE IV (A).

Effect of Variation of "Engine-cost Ratio." Best Values of r_e^{iii} *or* r_e^{iv}.

			M or N	.02	.04	.06	.08	.10	.15	.20
Class	I	Example	IV	$3\frac{1}{2}$	$3\frac{1}{4}$	3	$2\frac{3}{4}$	$2\frac{3}{4}$	$2\frac{1}{2}$	$2\frac{1}{4}$
"	II	"	VII	...	2	2	$1\frac{3}{4}$	$1\frac{3}{4}$	$1\frac{3}{4}$	$1\frac{1}{2}$
"	II	"	X	...	4	$3\frac{3}{4}$	$3\frac{1}{2}$	$3\frac{1}{4}$	$2\frac{3}{4}$	$2\frac{1}{2}$
"	III	"	XV	...	6	5	$4\frac{1}{4}$	4	$3\frac{1}{2}$	3
"	III	"	XVII	...	8	6	$4\frac{3}{4}$	$4\frac{1}{2}$	$3\frac{3}{4}$	$3\frac{1}{4}$
"	IV	"	XXI	...	$6\frac{1}{2}$	6	$5\frac{1}{2}$	$4\frac{3}{4}$	$3\frac{3}{4}$	$3\frac{1}{4}$
"	IV	"	XXIV	...	9	7	6	5	4	$3\frac{1}{2}$

These differences in the value of the ratio of expansion at maximum commercial efficiency are least where the exhaust wastes are greatest, and as their absolute values become smaller. Cases IV, X, XVII, XXIV have the same initial steam-pressure, and are seen to approximate toward the same value of r_e as the

value of M or N becomes greater, becoming, for the first two, and for the last two, nearly equal to the maximum value here taken.

It is obvious that the value r_e becomes a good gauge of the economical value of the engine, and that the greater these values and the nearer r_e^{ii}, r_e^{iii}, r_e^{iv} approach each other, in any given engine, the better the design.

It is now seen that we have here a method of determining the effect of variations of single variable quantities, while retaining all others constant—a method very greatly needed, but hitherto unknown.

The case just taken is an illustration of its application. The following is another instance of no less importance.

18. *Back Pressure as Modifying Economy.*

The Effect of Variation in Back Pressure may be studied, by means of this method of investigation, with the same facility.

Table V exhibits this effect for a wide range of cases.

TABLE V.

Effect of Variation of Initial Pressure and of Back Pressure. Best Values of r_e^1.

	$\frac{p_b}{p_1}$		$\frac{1}{3}$	$\frac{1}{4}$	$\frac{1}{5}$	$\frac{1}{6}$	$\frac{1}{8}$	$\frac{1}{10}$	$\frac{1}{15}$	$\frac{1}{20}$
Class I	No.	IV	$2\frac{3}{4}$	$3\frac{1}{4}$	$3\frac{1}{2}$	$3\frac{1}{2}$	...	...	...	...
" II	"	VII	$1\frac{1}{2}$	$1\frac{2}{3}$	$1\frac{2}{3}$	$1\frac{3}{4}$	$2\frac{1}{4}$	$2\frac{1}{2}$	...	...
" II	"	X	...	...	...	$1\frac{3}{4}$	$2\frac{1}{4}$	$2\frac{1}{2}$	3	4
" III	"	XVI	...	...	...	$4\frac{1}{2}$	6	7	9	11
" IV	"	XXII	...	...	...	6	6	8	12	15

These differences in value of r_e are obtained on the assumption that cylinder condensation and all other conditions remain unchanged while variation occurs in the back pressure. In all actual cases, the differences would be reduced by the fact that increased condenser-pressure and the reduction of chilling effect which comes with increase of back pressure so check exhaust waste that the ratio for maximum efficiency becomes somewhat increased, and these differences of ratio are thus lessened. The gain from this and other causes becomes sufficient at high pressures to justify the use of the simpler and less expensive non-condensing engine; it will be best appreciated after comparison of Class I with Class II.

19. *Illustrations of the Value of Results.*

In illustration of the use of this method and of the application of the results, we may observe, as in Table I, values of the ratio of expansion for maximum efficiency for any standard type of engine. Thus: Case III is that of an ordinary, standard, non-condensing, drop cut-off engine, steam 65 pounds ($5\frac{1}{3}$ atmospheres) by gauge, and the cut-off occurs, properly, at a little inside $\frac{1}{4}$ stroke; Case V is the same with steam at 105 by gauge (8 atmospheres) and its valve should close at a little inside $\frac{1}{5}$ stroke.

For maximum *commercial* efficiency those engines should "cut off" at about $\frac{1}{3}$ and $\frac{1}{4}$ respectively.

In the second class, Case VII is that of the old naval or modern very low-pressure river-boat engine carrying 25 pounds of steam by gauge ($2\frac{2}{3}$ atmospheres). The valve should drop so as to completely shut off steam at about half stroke to give minimum expenditure for coal, and a little later to give minimum cost on total account,* a result already reached by the builders of such engines.

Case VIII is that of some of our Hudson River steamboats (steam 45 by gauge), and these two ratios are found to be a little greater and a little less than 3. The irregularity of wheel which a short cut-off produces, however, makes it inadvisable to expand as much as this, even.

Case IX is often seen in mill engines; its valve closes at $\frac{1}{4}$ and $\frac{1}{3}$ for the cases taken. Above this pressure, a comparison of Class I with Class II shows that in the cases taken the non-condensing engine is about as economical as the other—a conclusion justified by Isherwood's comparison of Corliss engines†—but comparing values of r_e^{II} it is seen that the condenser may probably be exchanged for the heater with Classes III and IV only at some very high pressure not yet attained with jacketed engines of good design, while the ten per cent. gain obtained at the boiler by the higher temperature of feed given by the heater of the non-condensing engine, together with the differences in

* Engines of this class by good builders, having the "Stevens valve gear," close the valve at 6 feet on a 10-feet stroke, which, allowing for a little throttling, gives exactly this figure. Those fitted with the "Sickles cut-off," drop the valve as near half-stroke as possible; they cannot "follow" further.

† Journal Franklin Institute, September, 1881.

size of cylinder, brings down the pressure at which total efficiency becomes a minimum to some lower figure, which may be determined, by the method here given, for any given case.

Cases XV and XVI are commonly illustrated on transatlantic steamers and by the best compound pumping engines. The cut-off takes effect at $\frac{1}{8}$ or $\frac{1}{9}$ for maximum efficiency of engine and fuel, and at $\frac{1}{6}$ or $\frac{1}{7}$ for most economical expenditure of money,* figures already settled upon by the most successful builders.

Cases XII and XIII represent the most advanced practice in the use of high steam pressure, superheated steam, and reheating at the intermediate receiver, as is done in the pumping engines of Cowper, Corliss, and Leavitt. The best ratios of expansion are 12 and 15, if measured by duty attained and fuel saved, simply, and two-thirds those values give maximum efficiency of capital. Case XXIV represents most nearly the case of Corliss's best pumping engine, which lies between XXIII and XXIV; its best ratio of expansion lies between 9 and 10, if the Curve of Efficiency here taken for Class IV suits that case. If nine is the *real* ratio, the *apparent* cut-off will be nearly at one-tenth; while, for maximum efficiency of engine and maximum "duty," the valve should drop at about one-sixteenth stroke.

It should be carefully kept in mind that the measure of cost, in all problems relating to expense, as here treated, is the total cost per annum, without expansion, of all items of Class III, *i. e.*, variable with variation of steam supply.

The problem illustrated by the cases taken up in Table II would seem to be of rare occurrence. In fact, the writer has been able to imagine but two such cases:

(1.) Where the proprietor of an engine can rent power from an engine already set up with boiler power sufficient to supply an ample amount of steam, he will obtain the best return from his invested capital by delivering so much power at remunerative prices as will give the values r_e^{IV}, found in Table II. Cases IV, V, and VI are such as are most usual, the best point of cut-off averaging about $\frac{1}{3}$ stroke.

Had the power to be demanded been known, the proprietor would have done better to have put in a larger or a faster-running engine with a higher ratio of expansion, and would usually find it economical to alter the engine here assumed to

* *Vide* "Clark's Manual for Mechanical Engineers," pp. 888, 890.

be used—in the manner already described—if possible, so as to deliver the maximum power, working at the shorter cut-off.

(2.) The second is that of a naval engine intended to work with maximum efficiency at low power or long runs, and only requiring high power for short periods of time. It has sometimes been customary to design such engines to work with high ratios of expansion while cruising, and to develop full power with less expansion when in action, supplying a fan blast for the latter occasion. For such cases the best ratio at low power would be r_e^{II}, and it might be well to make the expansion variable through as wide a range as from r_e^{II} to r_e^{IV}, taken with extreme values of M and N. As already stated, in all ordinary work, the Ratio of Expansion at Maximum Commercial Efficiency is the ratio of expansion to be adopted for any engine.

The values here given for M and N are based on cost of fuel taken at \$5.00 per ton. The value of the ratios of expansion at maximum efficiency will be less at lower prices and greater at higher costs, the expenses of maintenance of plant being constant, since the values of cost of steam will be directly and of M inversely as the price of fuel. With coal at ten dollars per ton, M will be practically one-half the figures given above and the least ratio of expansion correspondingly increased as per Table V.

Table III may be consulted by the owner of steam-power for cases which, as is usual, fall within the given limits. For exceptional cases he, or his consulting engineer, can, when data are obtainable, always make his own curve of efficiency and obtain a practically exact solution of the case presented.

20. *Variation of Cylinder Condensation with Expansion.*

One other among the numerous problems capable of solution by this most prolific of methods promises, in the opinion of the writer, to prove, in the future, both interesting and important:

"*Given:* The method of variation of efficiency with varying ratios of expansion or proportions of steam used, to determine the method of cylinder condensation with varying values of $\frac{1}{r}$."

To solve this problem, construct the Curve of Efficiency, as A, D, E, O, Fig. 37, and draw the curves of adiabatic mean pressures for various values of x, as in dotted lines in that figure.

The points of intersection of these curves with the curve of

efficiency identify the ratios of expansion at which the total condensation amounts to the proportion due to the adiabatic line so cut.

In all problems of maxima or minima solved by the construction here given it will be observed that the item of quantity of expenditure made the independent variable is that dependent upon the quantity of steam or of fuel demanded by the engine.

21. *Problems solved by the Inspection of the Diagrams.*

An important class of problems of simple character may be solved with still greater ease and rapidity by the use of the Curve of Efficiency for the class of engine studied in any case, *e. g.:*

(1.) To determine the gain or decrease of power obtainable by change of ratio of expansion or point of cut-off, measure the ordinates of the curve at the present and at the proposed ratio of expansion; their relative magnitude will be a measure of the relative power of the engine at the two points of cut-off, if using the quantity of steam measured by the abscissas.

(2.) To determine the quantity of fuel or of steam, per hour per horse-power, to be gained or lost by change of the ratio of expansion, compare the value of ratios of abscissa to ordinate at the existing and proposed points of cut-off; their relation will be that of cost of power in steam or in fuel.

(3.) To determine the absolute amount of fuel or of steam per horse-power and per hour consumed, at any assumed rates of expansion, first calculate the consumption for the given engine as a thermodynamic problem simply, and multiply by the ratio, $\frac{y}{p_m}$, of the mean pressure in the perfect engine at the given expansion to that shown by the true Curve of Efficiency for the engine studied. Or, calculate the consumption for the engine working without expansion and without waste, and multiply by the ratio, $\frac{p_1}{p_m y}$, obtaining y and p_m from the diagram N, the given cut-off, and remembering that p_1 measures the mean pressure at full stroke of the given steam used *dry*.

It is evident that when costs of engine can be referred, as here taken, to the same unit of volume, the solution of the problem of maximum commercial efficiency is independent of size of

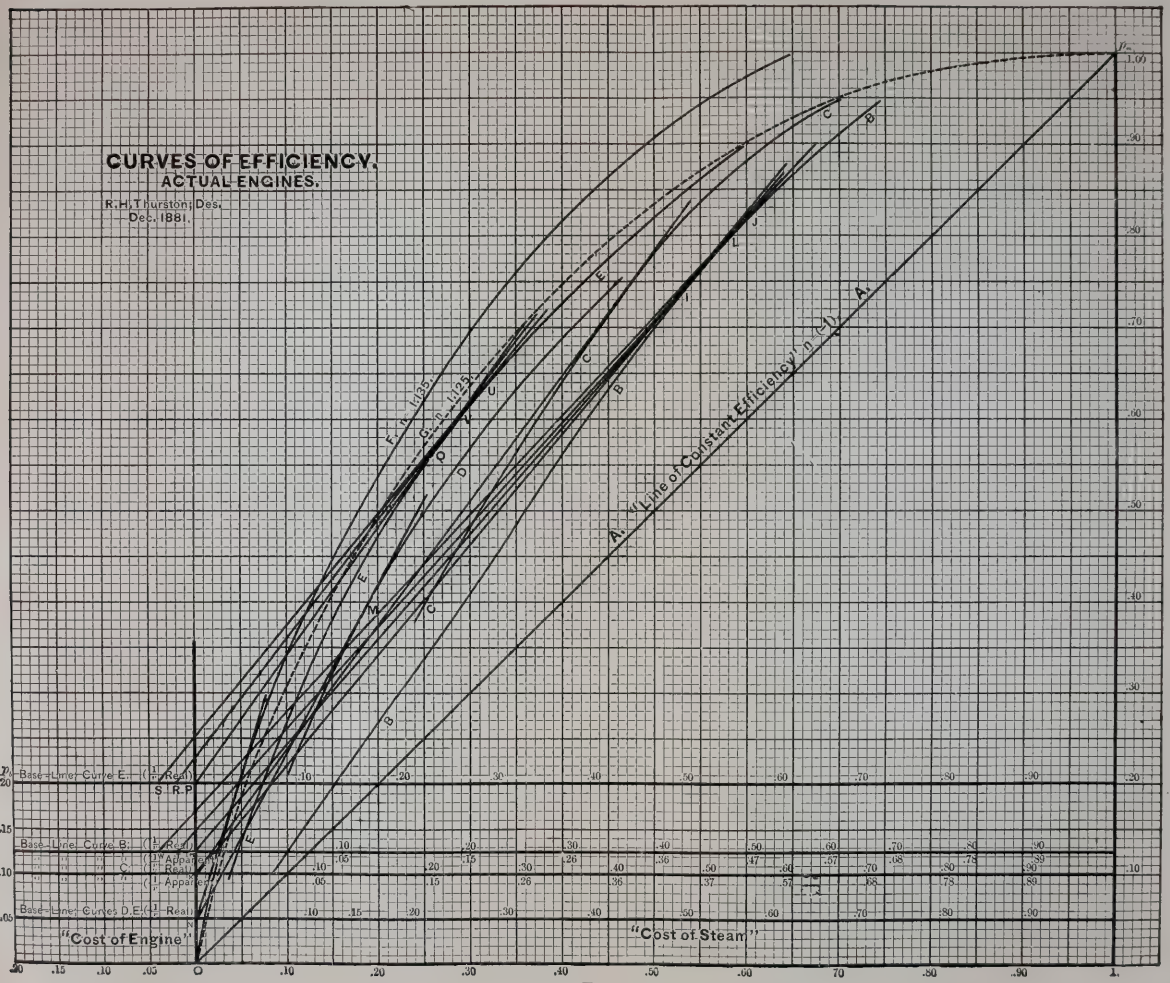

CURVES OF EFFICIENCY.
ACTUAL ENGINES.
R.H. Thurston, Des.
Dec. 1881.
"Line of Constant Efficiency" (η = η')
"Cost of Engine"
"Cost of Steam"

FIG. 38.

engine and of the absolute measure of power demanded, and hence applies to all engines of the same pattern.

22. *Conclusions.*

In view of what has preceded, it becomes obvious that the engineer proposing to write a specification for steam machinery on which bids are to be made with guarantee of performance should *first* determine the probable *Curve of Efficiency* for the kind of engine called for and solve the above problems relating to its economy. He should then prescribe the ratio of expansion at which maximum duty is to be obtained, as well as fix the duty expected in regular work, at which ratio the work done will be less than the regular working power of the machine. He must also indicate at what degree of expansion the engine will be required to do its ordinary work at maximum *commercial* efficiency, and should state what minimum commercial economy at that rate of work will be accepted. Finally, it should be prescribed that the engine should be capable, if its work should be increased, of attaining at least its "maximum efficiency of plant" with safety at maximum pressure, and with a specified efficiency, which should be reasonably high.

Thus fixing the ratio of expansion on the duty-trial, the builder is able to give an intelligently estimated guarantee of performance at highest efficiency; settling the ratio of expansion for maximum commercial efficiency in regular work fixes the proper size of engine, and the last specification secures ample strength of parts. Costs must be carefully estimated for the given locality. In what has preceded, the calculations have been based on cost of fuel estimated at $5.00 per ton, and labor at $2.00 to $3.00 per day, and interest at 6 per cent.

In laying out the curve of efficiency from experimental data it will be found necessary to be especially careful to establish the usually irregular scale of $\frac{1}{r^n}$, the points of cut-off, in their correct relation to the regular scale of steam expenditure and "cost of steam."

By the use of this, or some more exact method, the art of proportioning the steam-engine can be elevated to the rank of a branch of the Science of Engineering, and that part of that science which has hitherto been in a most unsatisfactory state, as viewed from the standpoint of the engineer engaged in its

application, may be found to take a comparatively complete and useful form.

The subject is here presented only provisionally. The effects of varying compression and of conditions relating to regulation, as well as many other minor conditions, remain to be studied. In a first survey of so broad a field, and especially where the needed data are so difficult to obtain and so uncertain as to accuracy, the writer cannot hope to have completely and exactly established all the results sought by him, and a revision of this work in the light of further investigation will probably ultimately lead to more correct and more valuable determinations.

It is even to be hoped, if not expected, that an exact theory of steam-engine economy may, at some early date, be produced, and that thus the engineer may be enabled to obtain solutions of such problems with all the precision that can ever be desired.

Added since the Meeting.

Note.—In this paper, the cost of engine is reckoned per cubic foot of cylinder. It is customary to reckon the value of large engines by the pound, and their weight by the cubic foot of cylinder. Weights per cubic foot of steam-cylinder are given in Haswell's *Pocket Book* (41st ed., pp. 605 *et seq.*) for various types.

In a paper by Professor Trowbridge,* which has come to the notice of the writer since the above paper was written, are given weights and prices of stationary engines. The latter become nearly constant when reckoned per cubic foot of cylinder, for sizes exceeding about 50 H. P.,—a fact of the more value since the figures are presented to sustain an opposite conclusion.

Where the costs do not so vary, this method is applicable by a system of approximation, assuming the probable cost of engine and repeating the work, using a corrected cost based on the first result.

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* Jour. Franklin Inst., July, 1882.

LXXV.

REPORT OF A TRIAL

OF

UPRIGHT BOILERS AND WORTHINGTON COMPOUND PUMPING ENGINE,

AT THE

ROXBURY PUMPING STATION, BOSTON, MASS.

JULY, 1879.

BY

J. S. COON, CAMBRIDGEPORT, MASS.

DESCRIPTION OF PLANT.

THE steam-generating apparatus employed during this trial consisted of two upright cylindrical tubular boilers, with internal furnaces, the boilers being located in brick setting. The product of combustion, after passing out of the top of either boiler, was conducted downward externally to the shell of the boiler, and in contact with the same, through flues in the brick setting. By referring to a sketch of the boilers it will be seen that considerable surface was available for superheating.

The principal dimensions of the boilers are as follows:

Diameter of circular shell,	84 inches.
Height, over all, about,	14 feet.
Diameter of circular grate,	69 inches.
Distance from grate to lower tube sheet,	2 ft. 5½ inches.
Number of wrought-iron tubes in each boiler,	220.
Length of each tube,	10 feet.
Internal diameter of each tube,	2¼ inches.
External " " "	2½ "
Water space about fire-box,	7 "
Grate surface in each boiler,	25.96 sq. feet.
" " " both boilers,	51.92 " "

Surface exposed to furnace gases in each boiler:

In fire-box,	64.3 sq. feet.
Internal surface in tubes,	1295.6 " "
Fire surface at top of boiler,	33.8 " "
" " external to shell of boiler,	112. " "
Total fire surface in one boiler,	1506. " "
" " " " both boilers,	3012. " "
Ratio of fire surface to grate surface,	58 : 1.
" " grate surface to internal cross-section of tubes.	4.27 : 1.

THE PUMPING ENGINE.

The pumping engine, whose duty was incidentally obtained at this trial, was a Worthington compound engine, of the ordinary type, having horizontal, direct-acting steam cylinders and pumps, there being two plungers, each driven by one high-pressure and one low-pressure cylinder.

The principal dimensions of the engines are as follows:

Diameter of high-pressure pistons, each,	21 inches.
" " low " " "	36 "
" " high-pressure piston-rods,	3 "
" " low " " "	$2\frac{1}{4}$ "
(There were two piston-rods to each low-pressure piston.)	
Diameter of pump plungers, each,	17.5 inches.
" " " " rods,	3. "
Stroke of engine No. 1,	3.165 feet.
" " " No. 2,	3.17 "
Mean stroke of both engines,	3.1675 "

Throughout the trial both engines made their full length of stroke.

METHOD OF CONDUCTING THE TRIAL.

The method adopted in conducting the trial is due to Mr. Richard H. Buel, of New York, and was the same as that used by Mr. Buel when testing the Lawrence and Pawtucket pumping engines.

Before commencing the trial the steam pressure was brought, in the boilers, to the minimum point that would readily enable the engine to do its work. The fires were then hauled, and the furnaces and ash-pits cleaned. The fires were then rekindled with wood, the steam pressure and water level being noted when the fires were lighted. Coal was added at once, and when the fires were in sufficiently good condition the engine was started and continued running until, after the last firing, the steam pressure had fallen to the point at which it stood when the fires were started, the water level being also the same. The engine was then stopped, the fires hauled, and the unconsumed coal picked out. This latter was deducted from the total coal supplied to the boilers during the trial, the remainder being charged to the experiment. The wood used in starting fires was also charged to the experiment, it being estimated as equivalent to four-tenths of its weight in coal.

The coal used during the trial was selected "Old Company's" Lehigh, of the very best quality.

During the trial the feed-water was supplied to the boilers directly from the street main, and its mean temperature was 74.56° F. Ordinarily the feed-water enters the boilers at 130° F., but as suitable connections could not be made for gauging the water after it was heated, it was supplied at the temperature of the street main. During the ordinary daily work the feed-water is heated by the exhaust steam from the direct-acting boiler feed-pumps.

It was inconvenient to weigh each draught of feed-water. It was gauged in a barrel fitted with fixed hook gauges, and by these uniformly filled and discharged each time, each draught weighing 374 lbs., as previously ascertained. From the measuring barrel the water was run into another, to which the pump connection was attached.

A mercurial column indicated the pressure per square inch in the force main, *i. e.*, the forward pressure against which the engine pumped. The mean of the recorded observations made on this gauge indicated a pressure of 78.703 lbs. per square inch.

The water supply for the main pumps was drawn from a street main under pressure, which assisted the engine in pumping. A mercurial column was used to indicate this back pressure. The mean of the observations taken from it, indicated a pressure of 27.11 lbs. per square inch.

The zero of the force-main gauge was 4.64 feet above the zero of the back-pressure gauge,—being equivalent to about 2.008 lbs. per square inch additional pressure. The head against which the engine pumped was therefore $(78.703 + 2.008) - 27.11 = 53.6$ lbs.

The boiler pressure gauge had been previously tested.

Tubes partially filled with oil were inserted into the flues to determine the temperature of the products of combustion as they left the boilers. Thermometers immersed in the oil indicated the temperature.

A thermometer was inserted into the main steam-pipe, about 10 feet from either boiler, to indicate the temperature of the steam.

A thermometer was inserted into the feed-pipe, between the feed-pump and the boilers, for indicating the temperature of the feed-water. A thermometer was also immersed occasionally

in the measuring barrel, during the early part of the trial, to obtain the temperature of the feed-water. But as its indications agreed exactly with those of the thermometer in the feed-pipes its use was subsequently discontinued.

A mercurial column indicated the amount of vacuum obtained in the condenser. This gauge indicated 0.4 inches too much.

Throughout the trial observations were made every thirty minutes on the engine counter (which indicated every four strokes of the engine) ; the force-main pressure gauge ; the back pressure gauge ; the vacuum gauge ; the steam pressure in boilers ; the temperature of the steam in the steam-pipe ; the temperature of the boiler flues ; the temperature of the feed-water, and the temperature of the engine-room.

Indicator diagrams were frequently taken from all four steam cylinders throughout the trial. The cards show a very uniform pressure in the high-pressure cylinders, not only throughout each single stroke, but also throughout the entire trial.

One man was engaged whose sole duty was to measure the feed-water.

RESULTS OF THE TRIAL.

Fires were hauled and ash-pits cleaned at 4.50 A.M. Fires were lighted at 5.07 A.M., with boiler steam-gauge at 29.5 pounds.

One hundred and fifty pounds of wood were used in each boiler to start fires.

The engine started at 5.50 A.M., with boiler steam-gauge indicating 44.5 pounds.

Engine run continuously till 9.21 P.M., when it was stopped,—the boiler pressure having fallen to 29.5 pounds, and the water standing in the glass gauge at the same point as when the fires were lighted, viz., 5.07 A.M.

The fires were hauled immediately after the engine was stopped.

Duration of trial, from the time the fires were lighted, at 5.07 A.M., till they were hauled, at 9.21 P.M., was sixteen hours and fourteen minutes.

Time during which engine was run, viz., from 5.50 A.M. till 9.21 P.M., fifteen hours and thirty-one minutes.

The following table gives the mean and total quantities as recorded in the log :

Mean pressure in force main, pounds per sq. inch,	78.703
Mean pressure in suction main, pounds per sq. inch,	27.11
Difference, pounds per sq. inch,	51.593
Correction for difference in zero points, pounds,	2.008
Mean corrected head against pumps, pounds per sq. inch,	53.6
Mean corrected vacuum, pounds per sq. inch,	12.55
Mean steam pressure at boiler gauge, pounds per sq. inch,	38.985
Mean temperature of the feed-water, F.,	74.561°
Mean temperature of the steam in main steam-pipe, F.,	352.5°
Mean temperature of the flue, boiler No. 1, F.,	317.3°
Mean temperature of the flue, boiler No. 2, F.,	316.9°
Mean temperature of the engine-room, F.,	84°
Total indications of engine counter,	11312
Total number of pump strokes,	45248
Total pounds of water evaporated,	29876.5
Total pounds of wood used to start fires,	300
Total pounds of wood used, in coal equivalent, 40 per ct.,	120
Total pounds of coal put into furnaces,	3711
Total fuel, in coal equivalent, pounds,	3831
At the close of the trial there were drawn from the grates, pounds,	511
Ditto from ash-pits, pounds,	256
Total ashes and unburned coal from both grates and pits, pounds,	767
Total unburned coal picked out from the above, pounds,	519
Total coal consumed, 3831 — 519 pounds,	3312
Total ashes, 766 — 519 pounds,	248
Percentage of ash in coal	7.48
Total combustible consumed, 3831 — 767 pounds	3064

ACTUAL DUTY OF THE PUMPING ENGINE DURING THE TRIAL.

Total head against pump, net, per square inch, pounds,	53.6
Mean area of plungers, square inches,	236.994
Total indications of the counter,	11312
Feet travelled by the plungers at each indication of the counter,	12.67
Total coal consumed, pounds,	3312

Hence duty was (foot-pounds per 100 pounds of coal),

$$\frac{236.994 \times 53.6 \times 12.67 \times 11312. \times 100}{3312.} = 54{,}970{,}264.$$

TRUE DUTY WITH WHICH THE ENGINE SHOULD BE CREDITED.

As previously stated, the feed-water is ordinarily supplied to the boilers at a temperature of 130° F., instead of the temperature named during the trial, viz., 74.561°. Hence the actual duty, as previously given, is less than the duty which should fairly be credited to the engine.

The thermal units imparted to one pound of water at 74.56° in converting it to steam at 53.69 pounds absolute pressure (38.985 pounds gauge), and superheating it to a temperature of 352.5° = 1150.78 thermal units.

The thermal units which would be imparted to one pound of water at 130° in converting it to steam at same pressure, and superheating as given above, = 1095.17 thermal units.

Hence, in consequence of using the cooler feed-water, the consumption of coal was increased in the ratio of 1150.78 to 1095.17, or 5.078 per cent., bringing the duty of the engine up to 57,761,517 foot-pounds.

EFFICIENCY OF THE PUMP.

From a mean of several sets of indicator cards taken at wide intervals during the trial, the percentage of the pressure on the pump plungers was 90.775 per cent. of the pressure on the steam pistons,—the water pressure on the plungers being taken at the same time the cards were taken from the steam cylinders.

SUPERHEATING.

Mean observed steam pressure at boilers, by gauge,	38.985 pounds.
Mean barometric pressure (29.938 inches mercury),	14.705 "
Mean absolute pressure of evaporation, per sq. inch,	53.69 "
Temperature of evaporation corresponding to this pressure,	285.7° F.
Mean observed temperature of steam in main steam-pipe,	352.5° F.
Degrees which steam was superheated,	66.8° F.
Thermal units imparted to each pound of steam in superheating (66.8 × .365),	24.38
Thermal units required to evaporate one pound of water from 74.56° F. to saturated steam at 53.59 pounds,	=1126.4
Increase due to superheating,	2.16 per cent.

HOURLY QUANTITIES.

Pounds of	coal,	213.7
"	combustible,	197.7
"	coal per square foot of grate,	4.115
"	combustible per square foot of grate,	3.807
"	coal per square foot of fire surface,	0.0794
"	combustible per square foot of fire surface,	0.0656
"	feed-water per square foot of fire surface,	0.64

EVAPORATION.

Pounds of water per pound of coal, at observed temperature and pressure,	9.027
Pounds of water that would have been evaporated per pound of coal at observed pressure, had feed-water been at 130° F.,	9.463
Pounds of water evaporated per pound combustible at observed temperature and pressure,	9.7508
Pounds of water evaporated per pound of combustible at observed pressure, had feed-water been supplied at 130° F.,	10.22
Pounds of water evaporated per pound of coal from and at 212° F., neglecting superheating, (Factor of evaporation being 1.1648.)	10.515
Pounds of water evaporated per pound of coal from and at 212° F., taking into account the superheating,	10.742

The quantity 10.515 represents the actual evaporation from and at 212° F. The quantity 10.742 represents what the evaporation would have been if the steam had been sent to the engine dry saturated, and supposing the products of combustion to have been cooled to an equally low degree.

Pounds of water evaporated per pound combustible, from and at 212° F., neglecting superheating,	11.358
Pounds of water evaporated per pound combustible, from and at 212° F., taking account of the superheating,	11.603
Pounds of water evaporated per hour, per square foot of heating (fire) surface, neglecting superheating,	0.745
Pounds of water evaporated per hour, per square foot of heating (fire) surface, taking account of superheating,	0.759

The factor of evaporation given above, viz., 1.1648, is based on the observed temperature of feed-water, viz., 74.561° F., and on the temperature of evaporation corresponding to the mean observed boiler pressure, viz., 38.985 pounds gauge. Taking into account the superheating, the factor of evaporation becomes 1.1864.

HORSE-POWER DEVELOPED.

Area of pump plungers, mean, square inches,	236.99
Head against pump, pounds per square inch,	53.6
Mean indications of counter per minute,	12.15
Feet travelled by plungers per each indication of counter,	12.67
Hence, net horse-power $= \frac{236.99 \times 53.6 \times 12.15 \times 12.67}{33000} =$	59.26
The efficiency of the engine being, as previously given, 0.9077, the indicated horse-power $= \frac{59.26}{.9077} =$	65.28

PERCENTAGE OF BOILER PRESSURE REALIZED IN HIGH-PRESSURE CYLINDERS.

The mean pressure above the atmosphere from all the high-pressure cards was, pounds per square inch,	15.5
Mean barometric pressure,	14.7
Mean absolute pressure realized in high-pressure cylinders,	30.2
Mean absolute pressure of steam in boilers,	53.69
Percentage of boiler pressure realized in high-pressure cylinders,	56.2

THE RELATIVE AMOUNT OF WORK DONE BY THE HIGH-PRESSURE AND LOW-PRESSURE CYLINDERS, RESPECTIVELY.

The following quantities may represent the amount of work done at each end of each steam cylinder for each engine, as given by the indicator cards :

High-pressure cylinder, back end, right-hand engine,	6916.8
" " piston-rod end, right-hand engine,	6609.4
" " total for both ends, right-hand engine,	13526.2
Low-pressure cylinder, back end, right-hand engine,	7573.0
" " piston-rod end, right-hand engine,	6968.5
" " total for both ends, right-hand engine,	14541.5
High-pressure cylinder, back end, left-hand engine,	6961.8
" " piston-rod end, left-hand engine,	6534.7
" " total for both ends, left-hand engine,	13496.5
Low-pressure cylinder, back end, left-hand engine,	7400.0
" " piston-rod end, left-hand engine,	7271.5
" " total for both ends, left-hand engine,	14671.5
Total high-pressure work done by both engines,	27022.7
Total low " " " "	29213.
Percentage of work done by high-pressure cylinders,	48.05
" " " " low-pressure cylinders,	51.95

POUNDS OF COAL AND WATER USED PER HORSE-POWER PER HOUR.

Pounds of coal per hour per net horse-power at observed pressure and temperature of feed-water,	3.606
Pounds of coal per hour per net horse-power, at observed pressure, if feed-water had been supplied at 130° F.,	3.432
Pounds of coal per hour per indicated horse-power, at observed pressure and temperature of feed-water,	3.27
Pounds of coal per hour per indicated horse-power, at observed pressure, if feed-water had been supplied at 130 F.,	3.11
Pounds of feed-water per hour per net horse-power,	32.53
Pounds of feed-water per hour per indicated horse-power,	29.52

STEAM ACCOUNTED FOR BY THE INDICATOR CARDS.

Assuming that the independent feed-pump took 1 per cent. of the feed-water supplied to the boilers, and assuming a clearance of 2 per cent. at the low-pressure cylinders, the indicator cards account for 87 per cent. of the feed-water supplied to the boilers.

It may be well to add that the object of this trial was to obtain additional data for deciding on the type of boiler to be used with the improved sewerage pumping engines, at Boston, and was authorized by Mr. Joseph P. Davis, then city engineer, Boston. The trial was conducted under the direction of Mr. E. D. Leavitt, Jr. The data taken from the Worthington engine were merely incidental. In order to avoid any imputation of unfairness, all observations were made jointly by myself and by Mr. Dexter Brackett and his assistants, from the City Hall, Boston.

Discussion.

Mr. Porter: It should be especially noted that the engine was not on trial. It was only the boiler that was on trial. The engine was a large engine performing very little duty. It was working under a boiler pressure of only fifteen pounds above the atmosphere, and, therefore, this performance, which was incidental, should not be recorded as any measure of the duty that the engine was capable of when it had a proper load, a load for which it was designed.

Mr. Nagle: These experiments having been instituted for the purpose of testing this boiler for its efficiency, with a view of its adoption for a sewage pumping-engine, it would seem that the test should have been made for a greater rate of consumption than that of which we have a record. These tests were made under the very exceptionally slow rate of combustion of less than four pounds of coal per square foot of grate, whereas the more common rate is ten to twelve pounds per square foot of grate. I desire to know if any tests were made that show the economy or efficiency at this more common rate of combustion?

Mr. Coon: No tests were made at a higher rate of combustion; but during these tests we used two boilers to supply the engine with steam, and when using only one, we found that the economy was not so good.

MR. NAGLE : Evidently when only one boiler was used for the engine, the rate of combustion must have been double that recorded, or about eight pounds per square foot of grate.

MR. COON : The economy is found not to be so good when one boiler is used as when two are used.

MR. NAGLE : But what the economy is when using only one boiler, when the rate of combustion is eight pounds per square foot of grate, we are not informed of.

MR. COON : No, sir.

MR. LE VAN : What is the difference between the flue temperature and the steam temperature?

MR. COON : The flue temperature was lower than that of the steam.

MR. LE VAN : I have found, where the flues exceeded thirty diameters in length, that anything exceeding that would tend materially to lessen the economy of the boiler. Had those experiments been made with a single boiler, the results as regards the consumption of fuel to work done would have been greater. Mr. President, Mr. Nystrom is present, and not being a member, I would ask the privilege be granted him of making a few remarks.

MR. PRESIDENT : If there is no objection, Mr. Nystrom may take part in the debate.

MR. NYSTROM : I came in at the end of the paper. There was 87 per cent. of water accounted for. I would ask what volume of steam is used?

MR. COON : Those volumes were taken from the tables in the work of Mr. Porter, and they were taken from that wholly because that is the most readily available table, so far as I am aware.

PROFESSOR ROBINSON : It strikes me that attention should be called to this apparently low duty,—fifty-four million foot-pounds. The circumstances in this case are all unfavorable for high duty. I think that point should not be overlooked. It is in favor of the pump that it should be as high as that under the circumstances.

LXXVI.

NOTE ON THE ECONOMY OF THE WINDMILL AS A PRIME-MOVER.

BY

ALFRED R. WOLFF, M.E., NEW YORK CITY.

In the course of professional work I have repeatedly had occasion to investigate the question of the impulse of wind upon windmills, and to observe the economical performance of the latter. From time to time I have published various results of these investigations, but have not given a record of the actual economy of the windmill, the subject proper of this note. Before however, setting forth the special economy in the use of the windmill as a prime-mover for small powers, it is well to refer briefly to some publications which may be of interest in connection with the general subject.

For the early history of windmills, and a description of European windmills, Fairbairn's *Mills and Millwork* may be consulted to advantage. For a description of the details of American windmills, see article on Windmills in Appleton's *Cyclopædia of Mechanics*, 1880. For an account of experiments on windmills see Smeaton's *Miscellaneous Papers*, and Coulomb's *Théorie des Machines Simples*. For the best angles of impulse and "weather," for windmill blades, see *Engineering and Mining Journal*, October 7th, 1876, and Appendix I of this note. The question of the impulse of wind upon windmill blades involves, too, the consideration of the relation between the velocity and pressure of the wind. A concise summary of this question, useful to no small extent in its reference to the journals containing the original publications of those who have given the subject attention, will be found in a paper by Mr. F. Collingwood, C.E., read before the American Society of Civil Engineers, April 6th, 1881, on *An Examination into the Method of Determining Wind Pressures*. In Appendix II of this note will be found the tabulated result of the writer's own work in this connection, in which the effect of temperature has received its due consideration. In the *Journal of the Scottish Meteorological Society*, 1880, Mr. F. Stevenson describes some interesting experiments tending to show the effect

of the height of observation above the ground on the relative velocity and pressure of wind. (See also *Engineering*, January 14th, 1881.)

Having thus indicated some of the publications where can be studied those considerations which affect the construction of windmills, and which to some extent determine as well their efficiency, I propose now to direct attention to the demonstration of the fact that whatever improvement in efficiency be possible in the future, windmills, as at present constructed, are the most economical prime-movers for those uses for which they are specifically designed.

In this demonstration, conclusions will be based only on observed facts or actual running results. I am enabled to do this inasmuch as some five years ago one of the most prominent windmill manufacturers came to me with a few scattered data of actual performances of his mills, which, however, were sufficient by means of deductions and analogy from theoretical principles, to warrant the preparation of the following:

Designation of mill.	Velocity of wind in miles per hour.	Revolutions of wheel.	Gallons of water raised per minute to an elevation of						Equivalent actual useful horse-power developed.	Average number of hours per day during which this result will be obtained.
			25 feet.	50 feet.	75 feet.	100 feet.	150 feet.	200 feet.		
8½ ft. wheel.	15 to 20	70 to 75	6.162	3.016	.....	.....	.....	.....	.04	8 to 10
10 ft. wheel.	15 to 20	60 to 65	19.179	9.563	6.638	4.750	.....	.....	.12	8 to 10
12 ft. wheel.	15 to 20	55 to 60	33.941	17.952	11.851	8.485	5.680	.....	.21	8 to 10
14 ft. wheel.	15 to 20	50 to 55	45.139	22.569	15.304	11.246	7.807	4.998	.28	8 to 10
16 ft. wheel.	15 to 20	45 to 50	64.600	31.654	19.542	16.150	9.771	8.075	.41	8 to 10
18 ft. wheel.	15 to 20	40 to 45	97.682	52.165	32.513	24.421	17.485	12.211	.61	8 to 10
20 ft. wheel.	15 to 20	35 to 40	124.950	63.750	40.800	31.248	19.284	15.938	.78	8 to 10
25 ft. wheel.	15 to 20	30 to 35	212.381	106.964	71.604	49.725	37.349	26.741	1.34	8 to 10

Since the preparation of this table, over a thousand windmills have been sold on its guarantee, and in all cases the actual results obtained, both in this country and elsewhere, did not vary sufficiently from those above presented to cause any complaint whatever; a proof that the results, as tabulated, are very close, or certainly not too high. If it be claimed that the horse-power developed appears small, from the standpoint of a (false) prevalent popular opinion, it should be observed in response that the actual results noted in the table are in close agreement with those obtained by theoretical analysis of the impulse of wind upon windmill blades. The manufacturer's own observations,

during the past five years, have led him to conclude that they are correct. It will, therefore, be just to base the economy of the windmill as prime-mover on the performances recorded in this table, and the expense of obtaining the power will be presented further on.

Conceding for a moment its economy, the possible employment of the windmill as prime-mover is dependent as well on other considerations. The objection urged against the use of windmills is the uncertainty of the motive fluid—wind; but we will see that this objection serves not to prevent, but only to restrict, the use of the windmill as prime-mover. Of course, it must be acknowledged that there are minutes and hours of total calm, and this restricts the employment of the windmill to such purposes, where either the nature of the work done by the wind mill allows of its being suspended during a calm, as work on a farm, for instance, or where the work can be stored, as in pumping water for a variety of purposes, or in compressing air, or, as was lately proposed by Sir William Thomson,* for storing electricity by means of dynamo machines and electrical accumulators. There is another restriction which goes into practical effect, namely, that the large size of a windmill for a given power makes it practically desirable only to be used for small powers, but actually it is only designed for the use of small powers, usually between $\frac{1}{2}\frac{1}{5}$ and 4 horse-power;† and for such powers it will be shown in this note that it is the most economical and serviceable prime-mover for the purposes for which it is designed.

The difficulty urged by Sir William Thomson against its adoption, in its present state of development, for storing electrical accumulators, is the *first cost* of the windmill, but this was doubtless an oversight,‡ for the *interest* on the capital expended, and

* Presidential address "On the Sources of Energy in Nature available to Man for the Production of Mechanical Effect," delivered before Section A of the British Association for the Advancement of Science, 1881.

† Coulomb, in his experiments with a windmill of four sails, 70 feet in diameter, breadth of sails, $6\frac{5}{8}$ feet, the wind blowing at a velocity of fifteen miles per hour, obtained an actual useful result equivalent to about 7 horse-power.

‡ In the same paper Sir William Thomson, in estimating the cost of utilizing the power of Niagara Falls for electric lighting, correctly considers the interest on first cost in determining the economical aspect of the question. The oversight, noted in the text, becomes important and worthy of mention only inasmuch as any statement of so distinguished and justly-esteemed an authority

not capital itself, becomes one of the items of current expense in judging of the economy of prime-movers, and, as will become evident from the contents of this note, the question of expense of producing power will not prove an objection, but, on the contrary, the best reason for the introduction of windmills to charge electrical accumulators.

It must be specially mentioned that experience has shown that the wind blows fast enough to run the windmill up to the regulating speed in the above table on an average of eight to ten hours per day of twenty-four hours, and our estimate of work done and expense of power will be based on an actual running of only eight hours per day.

The current expense of any prime-mover, or the cost of obtaining the horse-power developed per unit of time, which alone should form the basis of a comparison of the economy of different prime-movers, consists principally of interest, repairs, and depreciation of plant, cost of fuel, oil, and attendance. In windmills the cost of fuel is zero, wind being a free gift of nature. The attendance required for the self-regulating windmill, designated in the above table, amounts only to filling the oil-cups three or four times a month, the work of a few minutes, which any one can attend to. If any account is to be taken of this service, an allowance of fifteen cents a month would really be quite extravagant. In the following table such allowance has been made. Experience has shown that the repairs and depreciation items, jointly, are amply covered by 5 per cent. of the first cost, per annum. Interest is calculated at 5 per cent. per annum. The oil used is a very small quantity—a few gallons per year—and is allowed for in the table according to the size of mill. All the items of expense, including both the interest and repairs, are reduced to the hour by dividing the costs per annum by $365 \times 8 = 2920$, the interest, etc., for the twenty-four hours being charged on the eight hours of actual work. By multiplying the figures in column 5 by $\frac{365 \times 8}{100 \times .05} = 584$, the first cost of the windmill in dollars is obtained.

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as Sir William Thomson, is apt to be accepted on the basis of authority alone; and it must be added that the great caution usually displayed by the most eminent living English physicist entitles him *prima facie* to this mark of consideration.

TABLE SHOWING ECONOMY OF THE WINDMILL.

1	2	3	4	5	6	7	8	9	10
Designation of mill.	Gallons of water raised 25 feet per hour.	Average number of hours per day during which this quantity will be raised.	Equivalent actual useful horse-power developed.	Expense of actual useful power developed, in cents per hour.					Expense per horse-power, in cents per hour.
				For interest on first cost. (First cost, including cost of windmill, pump, and tower. 5 per cent. per annum.)	For repairs and depreciation. (5 per cent. of first cost, per annum.)	For attendance.	For oil.	Total.	
8½ ft. wheel.	370	8	.04	0.25	0.25	0.06	0.04	0.60	15.0
10 ft. wheel.	1,151	8	.12	0.30	0.30	0.06	0.04	0.70	5.8
12 ft. wheel.	2,036	8	.21	0.36	0.36	0.06	0.04	0.82	3.9
14 ft. wheel.	2,708	8	.28	0.75	0.75	0.06	0.07	1.63	5.8
16 ft. wheel.	3,876	8	.41	1.15	1.15	0.06	0.07	2.43	5.9
18 ft. wheel.	5,861	8	.61	1.35	1.35	0.06	0.07	2.83	4.6
20 ft. wheel.	7,497	8	.79	1.70	1.70	0.06	0.10	3.56	4.5
25 ft. wheel.	12,743	8	1.34	2.05	2.05	0.06	0.10	4.26	3.2

The number of gallons pumped by the 30-foot and 35-foot mills and larger sizes and the economy of the same are not given in the above table, for the number of larger mills in operation is not sufficient to insure the authenticity of the results thus far obtained. The performance of the 30-foot mill, as far as observed, seems to gravitate to a pumping capacity equivalent to 2.4 horse-power, and an expense of 2.5 cents per horse-power per hour.

When the figures in the table are contrasted with the cost of pumping the same amount of water by other prime-movers, where in addition to expense of interest, repairs, depreciation, and oil, there are the greater expenses of fuel and attendance, and often extra insurance on property, owing to the use of steam, the economy of the windmill must be evident to all.

To recapitulate: The figures given in the body of this note are the results of actual experience with hundreds of windmills, and as such, it was believed, would not be without interest. They prove conclusively that at the present time windmills are the most economical prime-movers for the powers and purposes outlined in this note, and for which they are usually designed.

Appendix I.

In a "Dissertation on the Theory and Practice of Windmills," published in the *Engineering and Mining Journal*, October 7th, 1876, the writer developed the formula:

$$\tan a = \frac{v}{c} + \sqrt{1 + \left(\frac{v}{c}\right)^2}$$

from which the best angle of impulse might be ascertained.

In this formula

a represents the angle of impulse of the wind upon the windmill blade (or sail), at any point of the blade, for maximum effect.

v = the velocity of the blade (at such point) in feet per second.

c = the velocity of the wind in feet per second.

The accompanying diagram (Fig. 39) is the graphical interpretation of that formula, the curves showing the best angles of impulse and "weather." The angle of "weather" is the complement of the angle of impulse, and is the angle which an element of the blade or sail makes with its plane of motion. Since there is no difference of effect between that caused by the blades moving against the air, and that caused by the air (or wind) striking upon the blades (assuming the same velocity in both cases), the angles given in the diagram will be found to be those of maximum efficiency for ventilating purposes as well as for windmills.

In the above diagram, the ordinates represent the best angles of weather and impulse, expressed in degrees, and the abscissas the ratio of the velocity of the wind to the velocity of the windmill blades. Thus, assuming the velocity of the wind to be 31.416 feet per second, the diameter of the wheel to be 35 feet, and the number of revolutions per minute to be made to equal 30, the velocity of the wind-wheel at a point $2\frac{1}{2}$ feet from the centre of the shaft will be 7.854 feet per second; at 5 feet from the centre, 15.708; at $7\frac{1}{2}$ feet, 23.562, etc., and the ratio of the velocity of the wind to the velocity of the sail $\frac{v}{c}$ will at $2\frac{1}{2}$ feet from the centre of shaft equal .25; at 5 feet, .50; at $7\frac{1}{2}$ feet .75, etc. The best angle of weather equals, therefore, at a distance $2\frac{1}{2}$ feet from the centre of the shaft, 38°; at 5 feet from the centre, 32°; at $7\frac{1}{2}$ feet, 27°, etc.; and the best angle of impulse equals, at a distance of $2\frac{1}{2}$ feet from the centre of the shaft, 52°; at 5 feet from the centre, 58°; at $7\frac{1}{2}$ feet, 63°, etc.

Appendix II.

TABLE SHOWING RELATION BETWEEN VELOCITY AND PRESSURE OF WIND.

Velocity of Wind.		Pressure of wind in pounds per square foot of plane surface, perpendicular to its course, when $P = 2116.5$ and temperature of wind =					
Miles per hour.	Feet per second.	0 F.	20° F.	40° F.	60° F.	80° F.	100° F.
1	1.46⅔	.005371	.005147	.004940	.004750	.004574	.004410
2	2.93⅓	.021482	.020586	.019761	.019001	.018294	.017641
3	4.39½	.048335	.046318	.044465	.042751	.041166	.039694
4	5.86⅔	.085930	.082345	.079048	.076008	.073185	.070568
5	7.33⅓	.134271	.128668	.123514	.118758	.114335	.110267
6	8.80	.193354	.185287	.177867	.171017	.164675	.158784
7	10.26⅔	.263186	.252205	.242112	.232780	.224148	.216140
8	11.73⅓	.343767	.329423	.316228	.304050	.292774	.282265
9	13.20	.436283	.416945	.400243	.384828	.370555	.357305
10	14.66⅔	.537188	.514772	.494151	.475121	.457498	.441195
11	16.13⅓	.650036	.622908	.597955	.584923	.553600	.533815
12	17.60	.773645	.741357	.711656	.684244	.658865	.635301
13	19.06⅔	.908020	.870122	.835260	.803085	.773296	.745638
14	20.53⅓	1.053166	1.010206	.968770	.931449	.896879	.864814
15	22.00	1.209087	1.158616	1.112190	1.069347	1.029670	.992841
16	23.46⅔	1.375798	1.318354	1.265523	1.216763	1.171621	1.129707
17	24.93⅓	1.553273	1.488425	1.428786	1.373721	1.322751	1.275429
18	26.40	1.741556	1.668839	1.501951	1.540180	1.483066	1.429470
19	27.86⅔	1.940634	1.859596	1.785056	1.716260	1.652571	1.593439
20	29.33⅓	2.150516	2.060705	1.978095	1.901853	1.831270	1.765740
25	36.66⅔	3.362250	3.221749	3.092521	2.973261	2.862857	2.760359
30	44.00	4.845284	4.642662	4.456311	4.284344	4.125157	3.979371
35	51.33⅓	6.600829	6.324565	6.070498	5.836055	5.619046	5.417590
40	58.66⅔	8.630351	8.268791	7.936307	7.627948	7.345581	7.082012
45	66.00	10.935522	10.476877	10.055155	9.666070	9.305975	9.971746
50	73.33⅓	13.518265	12.950585	12.428668	11.947178	11.501614	11.088085
60	88.00	19.525304	18.702993	17.947145	17.250017	16.605025	16.006591
80	117.33⅓	34.981530	33.497300	32.133920	30.877150	29.715020	28.863716

In obtaining the above data, attention was paid to the facts that the pressure depends upon both the velocity and the density of the air, and that this density depends upon the temperature, the barometric pressure, and the pressure due to the motion of the air. This table is for the average height of the barometer ($P = 2116.5$ pounds per square foot), and for any other barometric pressure the figures in the table must simply be multiplied by the ratio of the said barometric pressure, reduced to its value for temperature of air of 32° F. to 2116.5. Thus, letting p_3 = barometric pressure at any absolute temperature t, then $p = \frac{p_3 \times t}{491.4}$, and the figures in the table corresponding to wind pressure must be multiplied by $\frac{p}{2116.5}$.

For details of the method by which the above table of pressures is obtained, see *Engineering and Mining Journal*, September 23d, 1876.

Discussion.

Mr. Root: I am glad to see this subject come up. I think in the future it will have a great deal of importance. The suggestion has been made to procure power by connecting windmills with electric wires, and also by compressing air into pipes and connecting mills together over a large tract of country, whereby the loss from calms would be in a great measure neutralized, the wind probably blowing in one place while it was calm in another. It would only be a question of covering sufficient territory, to secure constant power. I think that in the future this subject will receive a great deal of attention, and that the winds will be found to be one of the most valuable sources of power. I think it deserves a far larger share of the attention of engineers than it has received.

Mr. Strong: This subject of windmills is one to which I have given some little time. I spent three or four years in experimenting on the construction and operation of windmills for farm and railroad pumping, and I think Mr. Wolff's tables are very moderate in their estimate of power. In regard to the operation of railroad water stations, the first cost of a railroad water station with steam-power and sufficient tankage is in the neighborhood of two thousand dollars. The actual expense of running a water station of that kind is an engineer at a dollar and a half a day, which would amount to forty-five dollars a month, and about twelve to fourteen tons of coal a month, the whole cost amounting to the neighborhood of two thousand dollars for the operation of a single station. The first cost of putting up a water station, with sufficient tankage for using windmills, which require about three times the amount of tankage that steam-pumps require, is about twenty-five hundred dollars, nearly the same as the steam water station. As to attendance, one man on a line of road is able to attend to all the mills on that line. Now, I have seen places where the windmill is adopted. At one place on the Camden and Amboy road, where they kept a man constantly at work pumping for the small stations, we put a pumping station on, with a windmill with the same amount of tankage. It was near the coast, and the wind was very regular, and although they used the full amount of the tank every day, they were never out of water. Last summer I was in London, and Sir William Thomson read a paper before

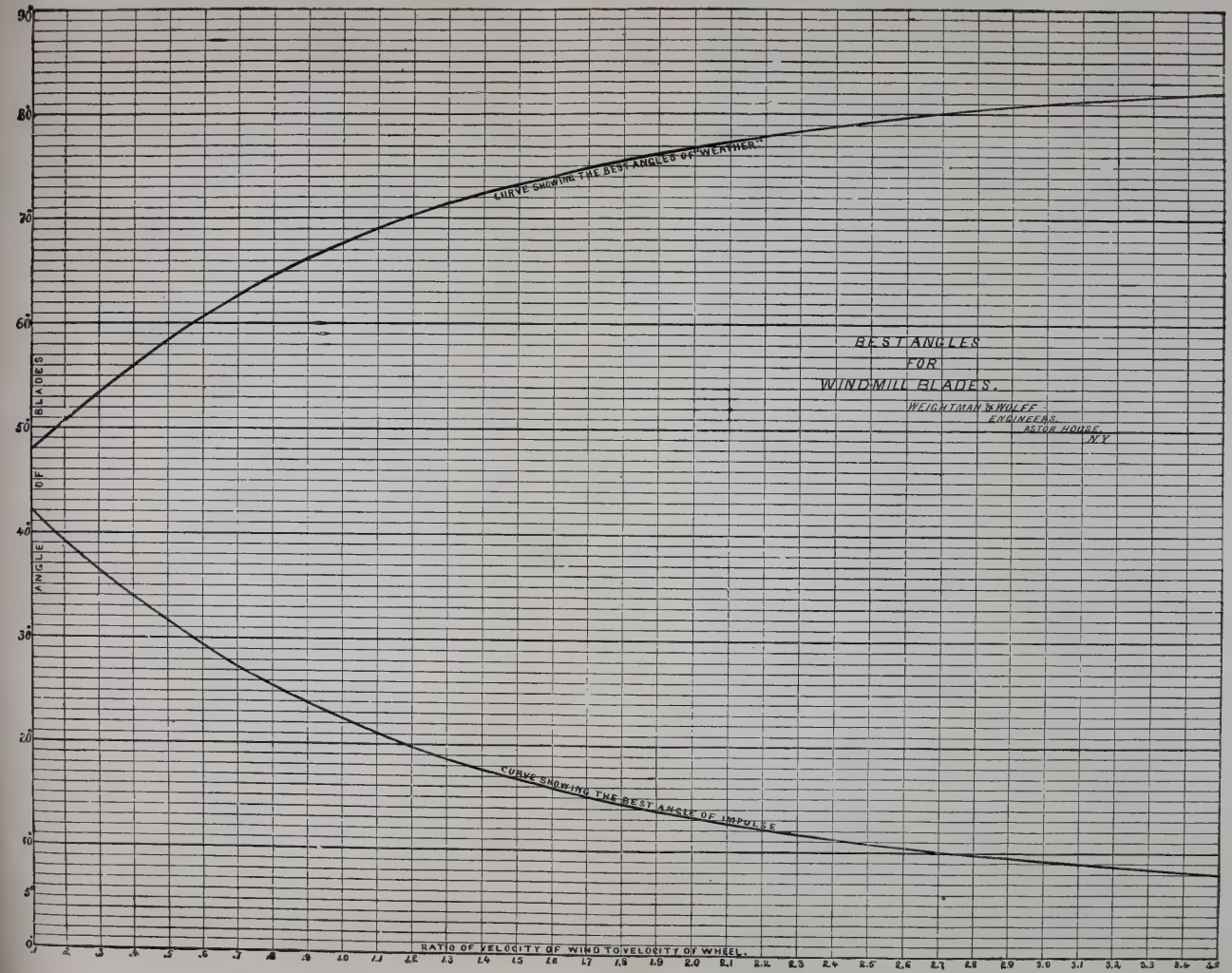
CURVE SHOWING THE BEST ANGLES OF "WEATHER"
BEST ANGLES
FOR
WIND-MILL BLADES.
WEIGHTMAN & WOLFF
ENGINEERS.
ASTOR HOUSE
N.Y.
ANGLE OF BLADES
CURVE SHOWING THE BEST ANGLE OF IMPULSE
RATIO OF VELOCITY OF WIND TO VELOCITY OF WHEEL.

FIG. 39.

the British Association, in which he remarked that he was sorry this question of windmills had not received more attention from engineers, and that he did not know, or did not think, that a practical windmill had ever been invented. The report was published in the London *Times*, and I wrote to Sir William Thomson that I had made some experiments, and I should be pleased to give him any information that I was able to furnish. He wrote me in reply, that he would be pleased to meet me in London the following day. I had quite a talk with him on the subject. I told him the experience I had had, and he was very much surprised to know that Americans had gone so far with windmills as they had, there being, practically, nothing done in this direction on the other side, the old-fashioned mill being used all over Europe, and very extensively in the north of England, not only for pumping, but for grinding. I venture to say that one-half of the flour used throughout Europe is ground to-day on those old-fashioned mills. I also had a conversation with Mr. Brush, of the Brush Electric Light Company, in Cleveland, not long ago. Mr. Brush had given this subject his attention, and, in connection with accumulators of electricity with which he is experimenting, he thinks it is quite practicable to adapt the windmill to the storage of electricity, and make it a very effective prime-mover.

GENERAL INDEX, VOLUME III.

[NOTE.—Titles of papers are printed in *italics;* names of authors and participants in debate are printed in SMALL CAPS.]

PAGE

Acceleration of moving parts Edison-Porter dynamos 233
Air heating in flues 72
Akerman on ferro-phosphorus alloys 93
Alloys of copper for burners and cartridges 99
Analysis of blast furnace slags 249
Annual cost of steam power 272
Application of the efficiency diagram 292
Appointment of U. S. Commission to test materials, T. Egleston 86
Armature of Edison-Porter dynamo 233
AUCHINCLOSS, W. S., averaging machines 220
Averaging Machines, W. S. Auchincloss 220

Babbit metal for journals 242, 243
Babbitt metals, pressure allowable on 241–243
Back pressure as modifying economy 301
BARR, W. M., disc. Test Commission 114
" " " Edison steam dynamo 233
" " " mineral wool 248
Bayles, J. C., tribute to Alex. Lyman Holley 37
BENNETT, T., on Pemberton Mill failure 27
Boiler and furnace efficiencies 262
Bond, G. M., standard gauge system 134
Built-up work in engine construction, Horace Lee 209
Burnham turbine wheel test 84

Cartridges and burners, alloys for 99
Chimneys, steam, internal corrosion of 248
Chronograph for engineering purposes, W. R. Eckart 197
Chronograph on Lowell pumping engine 205
Chronoscope used 200
Commission of 1868, to test iron for U. S. forts 93
" *to test iron and steel and other materials,* T. Egleston 86
Committee on experiments on steam boilers 7
" " horse-power of boilers 20
" " invitation to foreign engineers 6
" " National Bureau of Information and Standards 19
" " permanent location 6
" " standard gauges 14
" " tests of iron and steel 6
Comparator of Pratt and Whitney Co 134
Comparison of standard inches 137
Compress-cotton, failure of 114

PAGE
Compressed air by wind-mills ... 326
Coon, J. S., trial of upright boiler and engine at Roxbury pumping station 309
Corrosion of iron by caustic lime ... 247
" " " " mortar ... 247
" " steam chimneys ... 248
" by mineral wool ... 229
Cotton compress, failure of ... 114
Coupling for dynamo shaft ... 236
Coxe, E. B., at Holley Memorial Session ... 53
Cylinder condensation at different speeds ... 230
" " varies expansion ... 305

Determination of heating surface in ventilating flues, W. P. Trowbridge ... 72
Diaphragms in flues ... 82
Dynamo, the Edison-Porter ... 233

Economy of the wind-mill as a prime mover, A. R. Wolff ... 319
Economy of single-acting expansion engines ... 252
Eckart, W. R., chronograph for engineering purposes ... 197
Edison steam dynamo, C. T. Porter ... 233
Efficiencies, the several of the steam-engine ... 262
Efficiency diagram for engines ... 287
" of perfect ideal steam-engine ... 272
" of turbines as affected by firm of Gate S. Webber ... 84
Egleston, T., appointment of a U. S. Commission to test materials ... 86
" " disc standard gauge system ... 141
" " " mineral wool ... 249
Elasticity of long pump-rods ... 200
Electric storage by wind-mills ... 321
Emery, A. H., at Holley Memorial Session ... 69
Essay on Progress of Mechanical Science, 1824–1882, F. Fraley ... 214
Expansion of maximum efficiency ... 296
Expansion of steam and water without transfer of heat, A. Faber Du Faur 223

Faber, Du Faur, A., expansion of steam and water, without transfer of heat. 223
Fernie, F., at Holley Memorial Session ... 51
Ferro-phosphorus alloys ... 93
" silicon " ... 94
Flues, diaphragms in ... 82
Forging of steel *vs.* iron ... 211
Forgings, loss of weight in ... 209
Fraley, F., progress of mechanical science, 1824-1882 ... 213
Furnace and boiler efficiency ... 265

Gauge system, A standard, Geo. W. Bond ... 134
Glass decomposed by moisture ... 248

Heating surface in ventilating flues, W. P. Trowbridge ... 72
Hipp escapement ... 197
Hoadley, J. C., at Holley Memorial Session ... 58
" " specific heat of platinum ... 187

PAGE
Holley, A. L., memorial resolutions 11
" " memorial tribute, J. C. Bayles 37
Honorary members in perpetuity 4
Holloway, J. F., at Holley Memorial Session 60
Horse-power of Edison dynamo 240
Hunt, Robert W., at Holley Memorial Session 54
Hutton, F. R., note on the action of mineral wool as a non-conducting covering 244

Incorporation of the Society 3
Indicator cards of compound pumping engines 146
Internal corrosion of steam chimneys 248
Introduction to essay on mechanical progress, Coleman Sellers 213
Iron and steel industry of 1880 90

Joint Committee of Engineering Societies 9
Journals, Babbitt for 241

Kent, Wm., disc., built up work for engines 210
" " " U. S. Test Commission 115

Lanza, Gaetano, disc., U. S. Test Commission 117
Lead-screws for lathes 141
Letter on Pemberton Mill failure 27
Le Van, W. B., disc., Edison steam dynamo 241
" " " U. S. Test Commission 130
" " " trial of upright boilers at Roxbury 318

Memorial resolutions on A. L. Holley 11
" to U. S. Senate on Test Commission 110
" Session for A. L. Holley 9, 29
Metcalf, Wm., at Holley Memorial Session 55
" " disc., U. S. Test Commission 131
Mineral wool as a non-conductor, note on 244
Moore, Lycurgus B., at Holley Memorial Session 67

Nagle, A. F., disc., test of upright boilers at Roxbury 317
National turbine wheel test 86
Note on mineral wool as a non-conductor, F. R. Hutton 244
Note on the economy of the wind-mill as a prime mover, A. R. Wolff 319
Nystrom, J. W., disc., trial of upright boilers at Roxbury 318

Oxidation of iron by SO_2 gas 246

Parting-pots of ferro-phosper-silicons 94
Partridge, W. E., at Holley Memoral Session 71
" " disc., mineral wool 248
" " " U. S. Test Commission 130
Pemberton Mills, failure of 27
Platinum, specific heat of 187

PAGE
PORTER, C. T., Edison steam dynamo 233
" " at Holley Memorial Session..... 57
" " disc., trial of upright boilers at Roxbury 317
PRATT, F. A., disc., standard gauge system..... 140
Pressures on Babbitt metal..... 243
Pressure and velocity of wind, relation of..... 325
Proceedings, Philadelphia, 1882..... 1
Progress in mechanical science, 1824–82..... 214
Pump-rods, deformation and elasticity of..... 200

Railroad water-stations, wind-mills for..... 327
Rankine's diagram of efficiency..... 278
" *theorem of economy of single-acting engines*, W. P. Trowbridge.. 252
Refreshment of metals 93–98
Report of trial of upright boilers at Roxbury pumping station, J. S. Coon.. 309
Riveting *vs.* pin connections 117
ROBINSON, S. W., thermo-dynamics of certain forms of the Worthington and other compound pumping engines 141
" " disc, standard gauge system 141
" " " test of boilers at Roxbury 318
ROOT, JNO. B., disc., economy of the wind-mill..... 326
Roxbury Pumping Station, test of upright boiler at..... 309

SEE, HORACE, built-up work in engine construction 209
SELLERS, COLEMAN, introduction to essay on mechanical progress 213
" " at Holley Memorial Session 64
Several efficiencies of the steam-engine, R. H. Thurston..... 262
Sheet-iron diaphragms in flues 82
Silicates decomposed by heat..... 248
Slags decomposed by organic acids 251
SMITH, OBERLIN, disc., Edison steam dynamo 242
" " " U. S. Test Commission 112
Specific heat of iron..... 192
Specific heat of platinum, J. C. Hoadley..... 187
Standard gauge system, Geo. M. Bond..... 134
Steel *vs.* iron forgings 211
STRONG, GEO. S., disc., economy of the wind-mill..... 326
Sulphurous acid gas in mineral wool 246
Storage of power by wind-mills..... 322–327

Table of expansion of steam and water..... 228
Table of water raised by wind-mills..... 323
Tandem duplex compound engines 180
Temperature in ventilating flues 80
Test Commission, Appointment of a U. S..... 86
Testing machines at Watertown 87–116
Tests of Edison-Porter dynamo 239
Tests of steel, phosphides, and sulphides..... 131
Tests of turbines 85
Theorem of Rankine on single-acting expansion engine, W. P. Trowbridge 252

PAGE
Theory of corrosive action of mineral wool 245
Theory of efficiency of real engines 282
Thermo-dynamics of certain forms of Worthington and other compound pumping engines, S. W. Robinson..... 141
THURSTON, R. H., introduction to Holley Memorial Session..... 31
" " the several efficiencies of the steam-engine 262
" " disc., averaging machines 222
" " " built-up work in engine construction..... 211
" " " chronograph for engineering purposes 202
" " " Edison steam dynamo 243
" " " expansion of steam and water..... 231
" " " mineral wool 247
" " " U. S. Test Commission 117
Trial of upright boilers and engines at Roxbury Pumping Station, J. S. Coon 309
Tribute to A. L. Holley, J. C. Bayles..... 37
TROWBRIDGE, W. P., heating surface in ventilating flues..... 72
" " on a theorem of Rankine relating to the economy of single-acting expansion engines, first published in 1851 252
Turbines, efficiency of, as affected by form of gate, S. Webber 84

Upright boilers at Roxbury Pumping Station 309

Velocity and pressure of wind 325
Ventilating flues, heating surface in..... 72
" " temperature in 79
Ventilation by coil and blower compared 83

Water stations for R.R. by wind-mill 327
" raised by wind-mills..... 321
WEBB, J. B., belting to connect shafts which are not parallel and do not intersect 23
WEBBER, SAMUEL, efficiency of turbines, as affected by form of gate..... 84
Welds in iron, defective..... 93
Wind-mill as a prime mover, economy of..... 319
" for R. R. pumping..... 327
" storage of electricity 322
WOLFF, A. R., note on the economy of the wind-mill as a prime mover... 319
" " disc., expansion of steam and water 229
Wood columns, not loaded through axis 117
WOODBURY, C. J. H., disc., chronograph for engineering purposes..... 204
" " " mineral wool 247
" " " U. S. Test Commission 112

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HUNT, ROBERT W. ..... Supt. Albany & Rensselaer Iron and Steel Co., 128 First Street, Troy, N. Y.
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JOHNSON, LEWIS. ..... Julia Street, New Orleans, La.
JOHNSON, WILLIAM. ..... Lambertville, N. J.
JONES, DANIEL N. ..... Colorado Coal and Iron Co., South Pueblo, Col.
JONES, DAVID. . . Bureau of Steam Engineering, Navy Dept., Washington, D. C.
JONES, HENRY C. ..... Hilles & Jones, Wilmington, Del.
JONES, WILLIAM R. . . . Gen. Supt. Edgar Thomson Steel Works, Pittsburgh, Pa.
JONES, WASHINGTON. ..... No. 1632 15th Street, Philadelphia, Pa.

KAFFENBERGER, GUSTAV.....Black & Clawson Co., Hamilton, Ohio.
KENT, WM.....Babcock & Wilcox, 30 Cortlandt Street, New York City.
KETTELL, CHARLES W., Geo. F. Blake Mfg. Co.,
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KING, CHARLES I.....Madison, Wis.
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LEAVITT, E. D., JR.....604 Main Street, Cambridgeport, Mass.
LEAVITT, WM. A.....436 Walnut Street, Philadelphia, Pa.
LEGGETT, M. D.....620 Prospect Street, Cleveland, Ohio.
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LE VAN, W. BARNET.....3607 Baring Street, Philadelphia, Pa.
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MAIN, WILLIAM.....65 Henry Street, Brooklyn, N. Y.
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MARTIN, EDWIN H.....Chief Eng. Cleveland Rolling Mill Co.,
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MASON, WILLIAM.....72 Mansfield Street, New Haven, Conn.
MATLACK, DAVID J...I. P. Morris & Co., 1515 Marshall Street, Philadelphia, Pa.
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MILLER, LEBBEUS B.....Singer Mfg. Co., Elizabeth, N. J.
MILLER, LEWIS.....Aultman, Miller & Co., Akron, Ohio.
MILLER, REUBEN.....Miller, Metcalf & Parkin, Pittsburgh, Pa.
MILLHOLLAND, WM. K.....Supt. Falls Rivet Co., Cuyahoga Falls, Ohio.

MOFFAT, EDWARD S....Asst. Gen. Man. Lackawanna Iron and Coal Co ,
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MOORE, JOHN W.....Chief Engineer U. S. N., Honolulu, Sandwich Islands.
MORGAN, CHARLES H.....Supt. Washburn & Moen Mfg. Co., Worcester, Mass.
MORGAN, JOSEPH, JR.....Cambria Iron Works, Johnstown, Pa.
MORGAN, THOMAS R., SR.....Alliance, Ohio.
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MURPHY, EDWARD J.....Supt. Engineer, Colt's Armory, Hartford, Conn.
MURRAY, S. W.....Murray, Dougal & Co., Milton, Northumberland Co., Pa.

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NEWCOMB, CHAS. L.....Supt. Deane Steam Pump Co., Holyoke, Mass.
NEWTON, C. C.....Newton Machine Tool Works,
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NEWTON, ISAAC .....31 Chambers Street, New York City.
NICHOLSON, STEPHEN.....Providence, R. I.
NICHOLSON, W. T.....Nicholson File Co., Providence, R. I.
NICHOL, WILLIAM L.....Navy Department, Washington, D. C.
NORTON, HAROLD P., Asst. Eng. U. S. N., Bureau of Steam Engineering,
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ODELL, WM. H.....Yonkers, N. Y.

PALMER, GEORGE E..... 68 S. Canal Street, Chicago, Ill.
PARKER, WALTER E.....Lawrence, Mass.
PARKHURST, E. G.....Pratt & Whitney Co., Hartford, Conn.
PARKHURST, JOHN F..... Elm & Spruce Streets, Cleveland, Ohio.
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PHILLIPS, GEORGE H..... ....Hewes & Phillips Iron Works, Newark, N. J.
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PITKIN, A. J.....Schenectady Locomotive Works, Schenectady, N. Y.
PITKIN, JULIAN H.....C. Aultman & Co., Canton, Stark Co., Ohio.
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PUSEY, CHARLES W.....Pusey & Jones Co., Wilmington, Del.

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ROGERS, CHAS. L.....Designer and Draughtsman, Bethlehem, Pa.
ROOT, JOHN B.....Oak & Franklin Streets, Greenpoint, N. Y.
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SCHWEINITZ, P. B. DE.....Colorado Coal and Iron Co., South Pueblo, Col.
SCOTT, OLIN.....Bennington, Vermont.
SCOTT, IRVING M.....San Francisco, Cal.
SCRANTON, W. H.....Oxford Iron Co., Oxford, New Jersey.
SEE, HORACE....William Cramp & Sons' Ship and Engine Building Co., Philadelphia, Pa.
SEE, JAMES W.....Hamilton, Ohio.
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SELLERS, COLEMAN, JR.....332 N. 33d Street, Philadelphia, Pa.
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SMITH, GEORGE H.....Browne & Sharp Mfg. Co., Providence, R. I.
SMITH, HORACE S.....Gen. Supt. Joliet Steel Works, Joliet, Ill.
SMITH, JESSE M.....24 Burns Block, Detroit, Mich.
SMITH, OBERLIN.....Pres't Ferracute Machine Company, Bridgeton, N. J.

SMITH, SIDNEY L.....U. S. N., 195 West Newton Street, Boston, Mass.
SMITH, WILLIAM F.....Div. M. M. Central Pacific R. R., Carlin, Nev.
SNYDER, HENRY F.....Pardee, Snyder & Co., Watsontown, Pa.
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STEARNS, THOMAS B.....Colorado Machinery Co., Denver, Colorado.
STILLMAN, OSCAR B.....Boston Sugar Refining Co., Boston, Mass.
STIRLING, ALLAN.....H. R. O. & I. Co., Linlithgo, N. Y.
STETSON, GEORGE R....Supt. Morse Twist Drill and Machine Co.,
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STONE, HENRY B..... Asst. Gen. Man. C., B. & Q. R. R. Co., Chicago, Ill.
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SWASEY, AMBROSE.....Warner & Swasey, Cleveland, Ohio.
SWEET, JOHN E.....Straight Line Engine Co., Syracuse, N. Y.
SWEETLAND, WM. L.....126 Union Street, New Haven, Conn.

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TALLMAN, FRANK G..... .....Supt. Sweet Mfg. Co., Syracuse, N. Y.
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THOMAS, SAMUEL.....Catasauqua, Pa.
THOMAS, JAMES.....Davies & Thomas, Catasauqua, Pa.
THOMAS, JOHN.... .....Supt. Thomas Iron Co., Hokendauqua, Pa
THOMPSON, CHARLES T.....I. P. Morris Co., 1057 Richmond Street,
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TOWNE, HENRY R.....Pres. Yale & Towne Mfg. Co., Stamford, Conn.
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UEHLING, EDWARD A.....Bethlehem Iron Co., Bethlehem, Pa.
UNDERWOOD, F. H.....Pres. Underwood Mfg. Co., Tolland, Conn.

VENABLES, JOHN HAMSON.....Water Works, Toronto, Canada.

WALKER, JOHN.....Walker Manufacturing Co., Cleveland, Ohio.
WALLIS, JOHN MATHER...Supt. Motive Power P. B. & W. and B. & P. R. R.,
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WARD, JOHN F..... .....133 Mercer Street, Jersey City, N. J.
WARD, W. E.... .....Russell, Birdsall & Ward, Port Chester, N. Y.
WARNER, WORCESTER R.....Warner & Swasey, Cleveland, Ohio.

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WATTS, GEORGE W.....Dickson Mfg. Co., Scranton, Pa.
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WEBBER, SAMUEL S.....Lawrence, Mass.
WEBBER, WILLIAM OLIVER....Supt. Lawrence Machine Shop, Lawrence, Mass.
WEBSTER, AMBROSE.....Supt. Am. Watch Tool Co., Waltham, Mass.
WEBSTER, HOSEA, Jr....H. R. Worthington, 88 Liberty Street, New York City.
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WHEELER, NORMAN W.....Goss Marine Iron Works, Bath, Me.
WHEELOCK, JEROME.....Worcester, Mass.
WHITE, H. C.....Westinghouse Machine Co., Pittsburgh, Pa.
WHITE, JOSEPH J.....H. B. Smith Machine Co., 925 Market Street,
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WHITE, MAUNSELL.....Bethlehem, Pa.
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WILLIAMSON, WM. C.....Richmond & York Streets, Philadelphia, Pa.
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DOBSON, W. J. M.....McKesson & Robbins, 91 Fulton Street, New York City.
EVANS, EDWIN T.....L. S. Transit Co., 189 North Street, Buffalo, N. Y.
HALL, JOHN H.....T. R. Pickering & Co., Portland, Conn.
BAILEY, W. H.....20 Gold Street, New York City.

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PORTER, HOLBROOK F. J.....New Jersey Steel and Iron Co., Trenton, N. J.
RIDGELY, CHARLES.....Springfield Iron Co., Springfield, Ill.
ROBBINS, E. H.....Pittsfield, Mass.
SHARPE, LUCIAN.....Brown & Sharpe Mfg. Co., Providence, R. I.
SPERRY, CHARLES.....Port Washington, Queens Co., N. Y.
STOCKLY, GEO. W.....V. P. & Man. Brush Electric Co., Cleveland, Ohio.
TABER, EDWARD S.....Morse Twist Drill and Machine Co., New Bedford, Mass.
VANDERBILT, A., Supt. N. Y. & Cuba S. S. Line, 113 Wall Street, New York City.
WOOD WALTER.....R. D. Wood & Co., 400 Chestnut Street, Philadelphia, Pa.

Juniors.

BABCOCK, W. IRVING.....Del. Riv. Iron Ship and Eng. Works, Chester, Pa.
BURDSALL, ELWOOD, JR.....Port Chester, Westchester Co., N. Y.
CALDWELL, ANDREW J., Hyd. Works, Van Brunt & Rapelyea Sts., Brooklyn, N. Y.
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HILL, WILLIAM.....Collins Co., Collinsville, Conn.
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MARX, HENRY.....Hill, Clarke & Co., 800 N. 2d Street, St. Louis, Mo.
NEFTEL, KNIGHT.....Neftel & Churchill, 39 Broadway, New York City.
OWEN, EDWARD H., JR., S. B.....Lowell, Mass.
RIDGELY, WM. BARRETT.....Springfield Iron Co., Springfield, Ill.
SMITH, ALBERT W.....Kingsford Iron & Machine Co., Oswego, N. Y.
SMITH, JOHN WM.....Solvay Process Co., Syracuse, N. Y.
SUTER, GEO. A.....272 E. Houston Street, New York City.
TRUMP, EDWARD N.....Solvay Process Co., Syracuse, N. Y.
WALDEN, LIENAU.....202 South Front Street, Philadelphia, Pa.

Deceased

HENRY R. WORTHINGTON.....Dec. 17, 1880.
THEODORE R. SCOWDEN.....Dec. 31, 1881.
ALEXANDER L. HOLLEY.....Jan. 29, 1882.
ERASTUS W. SMITH.....June 12, 1882.
PETER COOPER, Honorary Member.....April 4, 1883.
JAMES PARK, JR.....April 21, 1883.
W. K. SEAMAN.....July 2, 1883.
REDMOND J. BROUGH.....July 21, 1883.
SIEMENS, C. W. Honorary Member.....Nov. 20, 1883.

RULES

OF THE

AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

OBJECTS.

ART. 1. The objects of the AMERICAN SOCIETY OF MECHANICAL ENGINEERS are to promote the Arts and Sciences connected with Engineering and Mechanical Construction, by means of meetings for social intercourse and the reading and discussion of professional papers, and to circulate, by means of publication among its members, the information thus obtained.

MEMBERSHIP.

ART. 2. The Society shall consist of Members, Honorary Members, Associates and Juniors.

ART. 3. Mechanical, Civil, Military, Mining, Metallurgical and Naval Engineers and Architects may be candidates for membership in this Society.

ART. 4. To be eligible as a *Member*, the candidate must have been so connected with some of the above specified professions as to be considered, in the opinion of the Council, competent to take charge of work in his department, either as a designer or constructor, or else have been connected with the same as a teacher.

ART. 5. *Honorary Members*, not exceeding twenty-five in number, may be elected. They must be persons of acknowledged professional eminence, who have virtually retired from practice.

ART. 6. To be eligible as an *Associate*, the candidate must have such a knowledge of, or connection with, applied science, as qualifies him, in the opinion of the Council, to co-operate with engineers in the advancement of professional knowledge.

ART. 7. To be eligible as a *Junior*, the candidate must have been in the practice of engineering for at least two years, or he must be a graduate of an engineering school.

The term "Junior" applies to the professional experience, and not to the age of the candidate. Juniors may become eligible to Membership.

ART. 8. All Members and Associates shall be equally entitled to the privileges of Membership, provided that Honorary Members who are not also Members or Associates and Juniors shall not be entitled to vote nor to be members of the Council.

ELECTION OF MEMBERS.

ART. 9. All candidates for admission to the Society, excepting candidates for honorary membership, must be proposed by at least three members, or members and associates, to whom they must be personally known, and be seconded by two others; the proposal to be accompanied by a statement in writing of the grounds of their application for election, including an account of their professional service.

ART. 10. All such applications and proposals received by the Council, up to thirty days before a regular meeting, shall, at least twenty days before such regular meeting be passed upon by the Council. The Secretary shall, at least twenty days before such regular meeting, mail to each member and associate, in the form of a letter ballot, the names of candidates recommended by the Council for election.

ART. 11. Any member or associate entitled to vote may erase the name of any candidate and return to the secretary such ballot inclosed in two envelopes, the inner one to be blank and the outer one to be indorsed by the voter.

ART. 12. The rejection of any candidate for admission as member, associate, or junior, by *seven* voters, shall defeat the election of said candidate. The rejection of any candidate for admission as honorary member by *three* voters shall defeat the election of said candidate.

ART. 13. The said blank envelopes shall be opened by the Council at any meeting thereof, and the names of the candidates elected shall be announced in the first ensuing meeting of the Society, and also in the first ensuing list of members. The names of candidates not elected shall neither be announced nor recorded in the proceedings.

ART. 14. Candidates for admission as honorary members shall not be required to present their claims; those making the nominations shall state the grounds therefor, and shall certify that the

nominee will accept if elected. The method of election in other respects shall be the same as in case of other candidates.

ART. 15. All persons elected to the Society, excepting honorary members, must subscribe to the rules and pay to the Treasurer the entrance fee and yearly dues before they can receive certificates of membership. If this is not done within six months of notification of election, the election shall be void.

ART. 16. The proposers of any rejected candidate may, within three months after such rejection, lay before the Council written evidence that an error was then made, and if a reconsideration is granted, another ballot shall be ordered.

ART. 17. The Council shall pass upon applications of juniors for membership, and shall order ballots upon such recommendations, in the manner hereinbefore described.

FEES AND DUES.

ART. 18. The initiation fee of members and associates shall be $15, and their annual dues shall be $10, payable in advance at the annual meeting; *provided*, that the persons elected at the meeting following the annual meeting shall pay $8, and persons elected at the meeting preceding the annual meeting shall pay $4, as dues for the current year. The initiation fee of juniors shall be $10, and their annual dues shall be $5, payable in advance. Any member or associate may become, by the payment of $150 at any one time, a life member or associate, and shall not be liable thereafter to annual dues.

ART. 19. Any member, associate, or junior in arrears may, at the discretion of the Council, be deprived of the receipt of publications, or stricken from the list of members, when in arrears for one year; *provided*, that such person may be restored to membership by the Council on payment of all arrears, or by re-election after an interval of three years.

OFFICERS.

ART. 20. The affairs of the Society shall be managed by a Council, consisting of a President, six Vice-Presidents, nine Managers, and a Treasurer, who shall be elected from among the members and associates of the Society at the annual meetings, to hold office as follows:

ART. 21. The President and the Treasurer for one year; and no person shall be eligible for immediate re-election as President who shall have held that office, subsequent to the adoption of these

rules, for two consecutive years; the Vice-Presidents for two years, and the Managers for three years; and no Vice-President or Manager shall be eligible for immediate re-election to the same office at the expiration of the term for which he was elected. *Provided* that, at the meeting for organization, the entire board of elective officers and managers shall be chosen, of whom the President, the Treasurer, three Vice-Presidents, and three Managers shall serve until the first Thursday of November, 1881; three Vice-Presidents and three Managers shall serve until the first Thursday of November, 1882, and three Managers shall serve until the first Thursday of November, 1883. The holding for the several terms shall be determined by lot among them.

Art. 22. A Secretary, who may or may not be a member of the Society, shall be appointed for one year by a majority of the members of the Council at its first meeting after the annual election, or as soon thereafter as the votes of a majority of the members of the Council can be secured for a candidate. The Secretary may be removed by a vote of twelve members of the Council, at any time after one month's notice has been given him by a majority of its members to show cause why he should not be removed, and he has been heard to that effect. The Secretary may take part in any of the deliberations of the Council, but, if not a member of the Society, shall not have a vote therein. His salary shall be fixed for the time he is appointed by a majority vote of the Council.

Art. 23. At each annual meeting after the first, a President, three Vice-Presidents, three Managers, and a Treasurer shall be elected, and the term of office shall continue until the adjournment of the meeting at which their successors are elected.

Art. 24. The duties of all officers shall be such as usually pertain to their offices or may be delegated to them by the Council or the Society; and the Council may, in its discretion, require bonds to be given by the Treasurer. At each annual meeting the Council shall make a report of proceedings to the Society, together with a financial statement.

Art. 25. Vacancies in the Council may occur by death or resignation; or the Council may, by vote of a majority of all its members, declare the place of any officer vacant, on his failure for one year, from inability or otherwise, to attend the Council meetings or perform the duties of his office. All vacancies shall be filled by the appointment of the Council, and any person so appointed shall hold office for the remainder of the term for which his predecessor

was elected or appointed; *provided*, that the said appointment shall not render him ineligible at the next annual meeting.

Art. 26. Five members of the Council shall constitute a quorum; but the Council may appoint an Executive Committee, or business may be transacted at a regularly called meeting of the Council, at which less than a quorum is present, subject to the approval of a majority of the Council, subsequently given in writing to the Secretary and recorded by him with the minutes.

Art. 27. No bill shall be paid for the Society, until it has been certified by the person authorized to contract it, and audited by committee on finance.

ELECTION OF OFFICERS.

Art. 28. At the regular meeting preceding the annual meeting, a nominating committee of five members, not officers of the Society, shall be appointed, and this committee shall, at least thirty days before the annual meeting, send the names of nominees to the Secretary, who shall at once mail the said list of names to each member and associate, in the form of a letter ballot.

Art. 29. In the election of Vice-Presidents, each member and associate may cast as many votes as there are Vice-Presidents to be elected. He may give all these votes to one candidate, or distribute them among more, as he chooses. Managers shall be voted for in the same way.

Art. 30. Any member or associate entitled to vote may vote by retaining or changing the names on said list, leaving names not exceeding in number the officers to be elected, and returning the list to the Secretary—such ballot inclosed in two envelopes, the inner one to be blank and the outer one to be indorsed by the voter. *Provided*, that no member or associate in arrears since the last annual meeting shall be allowed to vote until said arrears shall have been paid.

Art. 31. The said blank envelopes shall be opened by tellers at the annual meeting, and the person who shall have received the greatest number of votes for the several offices shall be declared elected.

MEETINGS.

Art. 32. The annual meeting of the Society shall be held in the City of New York, on the first Thursday in November, at which a report of the proceedings of the Society and an abstract of the accounts shall be furnished by the Council; the Council may

change the time of the annual meeting, and shall, in that case, give six months' notice to members and associates.

Art. 33. Two other régular meetings of the Society shall be held in each year, at such times and places as the Council may appoint. At least thirty days' notice of such meetings shall be mailed by the Secretary to members, honorary members, associates and juniors.

Art. 34. Special meetings may be called whenever the Council may see fit; and the Secretary shall call a special meeting at the written request of twenty or more members. The notices for special meetings shall state the business to be transacted, and no other shall be entertained.

Art. 35. Any member, honorary member or associate may introduce a stranger to any meeting; but the latter shall not take part in the proceedings without the consent of the meeting.

Art. 36. Every question which shall come before the Society shall be decided, unless otherwise provided by these rules, by the votes of a majority of the members and associates present, provided there is a quorum.

Art. 37. At any regular meeting of the Society, thirteen or more members and associates shall constitute a quorum.

Art. 38. The Council shall have power to decide on the propriety of communicating to the Society any paper which may be received, or to refer it back to its author for revision or amendment; also, to decide which of the papers read before the Society shall be printed in the *Transactions*. Before such paper appears in the *Transactions* of the Society, a revised proof of the paper and discussion shall be sent by the Secretary to the author, and, so far as practicable, to every member taking part in the discussion, with request that they call attention to any errors therein. When the Council shall so direct, printed copies of papers shall be distributed to the membership in advance of the meeting at which they are to be presented and discussed.

Art. 39. Intimation, when practicable, shall be given at a general meeting, of the subject of the paper or papers to be read, and of the questions for discussion at the next meeting.

Art. 40. The Society shall claim no exclusive copyright in papers read at its meetings, nor in reports of discussions, except in the matter of official publication with the Society's imprint, as its *Transactions*. The Secretary shall have sole possession of papers between the time of their acceptance by the Council and their reading, together with the drawings illustrating the same; and at the

time of such reading, or as soon thereafter as practicable, he shall have printed copies of such papers "subject to revision," with such illustrations as are needed for the *Transactions*, for distribution to the members and for the use of technical newspapers, American and foreign, which may desire to reprint them in whole or in part. The policy of the Society in this matter shall be to give papers read before it the widest currency possible, with a view to making the work of the Society known, encouraging mechanical progress and extending the professional reputation of its members.

ART. 41. The author of each paper read before the Society shall be entitled to twelve copies, if printed, for his own use, and shall have the right to order any number of copies at the cost of paper and printing; *provided*, that said copies are not intended for sale.

ART. 42. The Society is not, as a body, responsible for the statements of fact or opinion, advanced in papers or discussions, at its meetings; and it is understood that papers and discussions should not include matters relating to politics or purely to trade.

AMENDMENTS.

ART. 43. These rules may be amended, at any annual meeting, by a two-thirds vote of the members present; *provided*, that written notice of the proposed amendment shall have been given at a previous meeting.

INDEX TO AUTHORS.

	PAGE
Baldwin, Wm. J.	274
Collins, C. C.	268
Comly, Geo. N.	315
Curtis, Gram	239
Durfee, W. F.	311
Durfee, W. F.	368
Green, H.	217
Hayward, H. S.	136
Henning, G. C.	410
Holloway, J. F.	211
Hornig, J. L.	233
Kent, Wm.	249
Lanza, G.	119
Maynard, G. W.	351
Proceedings, New York, 1882	1
Proceedings, Cleveland, 1883	193
Rae, T. W.	321
Raymond, R. W.	35
Robinson, S. W.	150
Seaman, W. K.	106
Smith, O.	335
Sweet, J. E.	231
Sweet, J. E.	237
Thurston, R. H.	75
Thurston, R. H.	224
Thurston, R. H.	404
Towne, H. R.	288
Ward, J. E.	388
Webb, J. B.	165
Webb, J. B.	183
Webb, J. B.	367
Webber, S. S. & W. O.	227

TABLE OF CONTENTS.

PAGE

PROCEEDINGS OF THE NEW YORK MEETING OF 1882 1

Memorial Address—A. L. Holley. By R. W. Raymond, Ph.D. 35

Annual Address—The Mechanical Engineer. By R. H. Thurston..... 75

Rail-Cambering Arrangement of the Lackawanna Iron and Coal Co. By W. K. Seaman 106

DISCUSSION by Messrs. Durfee, Hunt, Robinson and Strong..... 115

An Account of Certain Tests of the Transverse Strength and Stiffness of Large Spruce Beams. By Gaetano Lanza..... 119

DISCUSSION by Messrs. Partridge, Egleston and Emery..... 131

Adjustable Cut-Off for Marine Engines. By H. S. Hayward..... 136

DISCUSSION by Messrs. Thurston and Holloway..... 140

Protective Value of Boiler Inspection. By F. B. Allen 142

DISCUSSION by Mr. Le Van..... 149

Back Pressure on Valves. By S. W. Robinson..... 150

Belting to Connect Shafts which are not Parallel and do not Intersect. By J. Burkitt Webb..... 165

A New Form of Steam Engine Indicator. By J. Burkitt Webb..... 182

DISCUSSION by Messrs. Smith, Emery and Holloway..... 186

PROCEEDINGS OF THE CLEVELAND MEETING OF 1883..... 193

The Marine Engine of the Lakes, and a Device for getting them off the Dead Centres. By J. F. Holloway 211

History and Development of Winding and Pumping Machinery in the Anthracite Coal Regions of Pennsylvania. By Howell Green.. 217

On a Newly Discovered Variation in the Effect of Prolonged Stress on Iron. By R. H. Thurston..... 224

A New Form of Balance Dynamometer. By S. S. & W. O. Webber... 227

A New Method of Constructing a Crank Shaft. By John E. Sweet.... 231

Economy by Subdivision in Installation and Operation of Power and Machinery under Varying Demand. By Julius L. Hornig..... 233

A New Method of Casting Flange Pipe. By John E. Sweet..... 237

Remarks upon the Ordinary Form of Bessemer Ingot Cranes. By Gram Curtis... 239

The Evaporative Power of Bituminous Coals. By William Kent..... 249

Balanced Valves. By C. C. Collins..... 268

On Standard Cast-iron Fittings. By Wm. J. Baldwin..... 274

DISCUSSION by Messrs. Le Van, Barr, Leavitt, Walker, Henning and Grant..... 280

Cranes: A Study of Types and Details. By Henry R. Towne 288

DISCUSSION by Messrs. T. R. Morgan, Walker, Collins, Smith, Capen, Leavitt and Durfee 302

Mechanism for Manœuvering Clutch Couplings. By W. F. Durfee... 311

DISCUSSION by Mr Walker..... 314

PAGE

Economy in Lubrication of Machinery. By Geo. N. Comly..... 315
Discussion by Messrs. Grant and Woodbury..... 317
Some of the Mechanism employed in Multiplex Telegraphy. By T. W. Rae..... 321
Spiral Springs—Compressible and Tensile. By Oberlin Smith..... 335
Discussion by Messrs. Robinson, Richards, Webb, Woodbury, Grant, Capen, Leavitt and Pickering..... 340
The Bower-Barff Rustless Iron Process. By Geo. W. Maynard..... 351
Discussion by Messrs. Henning, Smith, Le Van, Partridge, Weston, Leavitt and Root 363
Abstract of a Paper on Reuleaux's Kinematic Models. By J. Burkitt Webb..... 367
Balanced Vertical Engines. By W. F. Durfee..... 368
Discussion by Messrs. Henning, Leavitt, Scott, Hewitt, Le Van, Miller, Hamilton, Baldwin, Morgan, Comly and Sweet..... 380
Béton in Combination with Iron as a Building Material. By W. E. Ward..... 388
Discussion by Messrs. Grant, Woodbury, Le Van, Leavitt, Root, Weightman and Thompson..... 400
Note Relating to "Water-Hammer" in Steam Pipes. By R. H. Thurston..... 404
Discussion by Mr. Chas. E. Emery..... 407
Notes on Steel. By G. C. Henning..... 410
Appendix..... .. 420
Discussion by Messrs. Leavitt and Le Van..... 427

LIST OF ILLUSTRATIONS.

PAGE

Figure 1. General plan of cambering machine 118
" 2. Section through pair of rolls 118
" 3. Vertical section 118
" 4, 5, 6. Cambering machines 118
" 7, 8, 9. Rising grip-rolls 118
" 10, 11. Tilting guide-rolls 118
" 12. Operation of tilt and guide-rolls 118
" 13, 14. Straightening machine 118
" 15, 16. 17, 18. Hot-bed construction 118
Testing apparatus applied to spruce beams 120
Adjusting rod for marine cut-off 136
Releasing gear for marine cut-off 137
General side elevation for marine cut-off 138
Dash-pot for valve-stems in marine cut-off 139
Indicator diagrams from ferry-boat Baltimore 140
Diagram of effective pressure on slide valve 150
Diagram of downward pressure on slide valve 151
Device to show downward pressure on slide valve 154
Equilibrium lines of pressure on slide valve 156
Diagram for integration 157
Longitudinal section through slide valve 162
Diagram of Experiments on back pressure 164
Perpendicular tangent on quarter twist belts 166
Horizontal projection of pulleys on two shafts 167
Diagram to show exact positions of belt 167
Development of part of upper belt pulley 171
Diagram of differentials 172
Horizontal projection of curves of belt 174
Sectional projection of pulley tangents, etc 174
Partial plan and elevation of new indicator 182
Indicator card with oscillating admission line 183
Diagram from new indicator 184
Device for getting a marine engine off the centre 216
New balance dynamometer 230
Economy curve, engines for varying service 235
Mold and chill for cast flange pipe 239
New ingot crane 249
Porter-Allen valve 268
John F. Allen valve 269
J. E. Sweet valve 270
Collins' valve 271
Collins' new valve 272

PAGE

Robert Briggs' scale for fittings 279
W. M. Barr's elbow and tee 282
Chambered elbow 282
Section of Barr tee 283
Section of large tee 284
Mechanism for clutch—Plan 311
Mechanism for clutch—End elevation 312
Mechanism for clutch—Side elevation 313
Frischen's solution of duplex telegraphy 323
Duplex telegraphy by Frischen 324
J. B. Stearns' modification 325
Stearns' bridge duplex system 326
Stark's system, sending station 327
Stark's system, receiving station 329
Edison's quadruplex telegraphy 330
Gray's Harmonic system of telegraphy 333
Gray's multiplex telegraphy 334
Diagram to deduce formulæ for springs 341
Longitudinal section of Bower-Barff furnace 353
Transverse " " " " 355
Horizontal " " " " 358
" " " " " 360
Vertical " " " " 361
Horizontal " " " " 362
Elevations of balanced vertical engine 368
Bed-plate of balanced vertical engine 369
Pillow block of balanced vertical engine 370
Section of cylinder of balanced vertical engine 372
Cross-head of balanced vertical engine 373
Cross-head gibs of balanced vertical engine 374
Steam chest and valve of balanced vertical engine 375
Stuffing-box of balanced vertical engine 377
Balance cylinder of balanced vertical engine 379
View of béton house 390
Section of re-enforced béton beam 394
Section of béton house, to show flues 396
Passes for reducing steel ingots 415
Plate of tests from East River Bridge 416
Steel plate distressed by carelessness 418

PAPERS

OF THE

NEW YORK MEETING, 1882.

PROCEEDINGS

OF THE

AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

PROCEEDINGS OF THE NEW YORK MEETING, NOVEMBER, 1882.

COMMITTEES OF ARRANGEMENT.

Local.—Prof. W. P. Trowbridge, *Chairman;* F. B. Allen, S. W. Baldwin, J. C. Bayles, A. W. Colwell, C. W. Copeland, C. H. Loring, W. C. Hicks, C. W. Nason, W. H. Weightman, H. B. Miller, F. M. Wheeler, W. H. Wiley, A. Vanderbilt, C. C. Worthington, H. S. Hayward, S. McElroy, W. E. Ward, T. W. Rae, G. H. Robinson, G. H. Reynolds.

Executive.—Messrs. Copeland, Rae, Wiley.

Invitations and Receptions.—Messrs. Trowbridge, Bayles, Loring.

Excursions.—Messrs. Hayward, Loring, Worthington.

Hotel and Accommodation.—Messrs. Weightman, Vanderbilt, Wheeler.

Rooms and Places of Meeting.—Messrs. Ward, Nason, Rae.

Printing and Press Notices.—Messrs. Hicks, Rae, Miller.

The regular Annual Meeting of 1882 was opened by a Joint Session of the American Society of Mechanical Engineers with the American Society of Civil Engineers and the American Institute of Mining Engineers. The special session was called to listen to a Memorial Address in commemoration of Alexander Lyman Holley, and was held in the Turf Club Theater, at eight o'clock, on November 1st, 1882. On the stage with the President and the orator of the evening were Ex-Governor Holley, Mr. J. J. R. Croes, and Gen. G. S. Greene; Vice-Presidents Coxe and Trowbridge, and Secretaries Bogart, Drown, and Rae.

President Thurston, after calling the Convention to order, said:

It is not necessary that the Chair should state in detail the *raisons d'être* of this meeting. It is enough to say that the three great national societies of engineers, the American Society of Civil Engineers, the American Institute of Mining Engineers, and the

American Society of Mechanical Engineers, have gathered here to-night, at the close of All Saints' Day, on the eve of All Souls' Day, on that feast day, "of holy days the crest," as Lowell calls it, to do honor to a common colleague and a mutual friend, who has "gone before." We meet to honor, not "the *unknown* good who rest in God's still memory folded deep," but one whose great work is known of all, men and angels, who, as a man of genius, stood eminent among his fellows, and who, as a benefactor of his kind, stands preëminent in his day and generation—one whose good works shall endure through all time, and shall be more and more fruitful of blessings to mankind to the end.

And while we meet to do honor to his memory as one of the brightest ornaments of our noble profession, as a distinguished member of these societies, as an earnest co-worker in all plans that affected their prosperity, we feel that the heart is vastly more concerned than the head, and we would still more highly honor his memory as one whose superlative merit in his profession was eclipsed by the beauty of his personal character. We commemorate the loss, in him, of a beloved colleague and a never to-be-forgotten friend.

The committee, in arranging the ceremonies of this evening, have been peculiarly fortunate in being able to secure as the orator of the occasion the gentleman whom I now have the pleasure and the honor to present to you. On this evening, if on any evening of the year, we may hope and believe that our friend is permitted to be with us, and we may feel well assured that his spirit will find a perfect satisfaction in the choice which has been made. It will afford us all very great pleasure to be able to listen to the story of a life full of earnest strivings, of honest fealty to duty, of noble loyalty to friends, of a life full of good work and crowned with great successes, short though it was, from one who is so well fitted to comprehend, to appreciate, and to describe his work, from one who long worked hand in hand with him and at some of his greatest tasks, and especially from one who for many years was bound to him by the ties of a hardly less than fraternal love. Such a speaker needs not the powers of the orator. A plain, straightforward story on such an occasion and from such a narrator is highest eloquence.

I have the honor and the pleasure to present to the Convention Dr. Rossiter Worthington Raymond.

Dr. Raymond then delivered an abridgment of the Memorial

Address in commemoration of Alexander Lyman Holley, which appears in the Papers of the New York Meeting.

At the close of the oration, Mr. Bayles rose:

Mr. Bayles.—After such an address as that to which we have listened, this audience is in no mood for other remarks, and with a view to terminating this meeting properly, I would offer this resolution:

Resolved, That we tender our thanks to Dr. R. W. Raymond for his eloquent and instructive address, and for the labor which has enabled him to bring together so many facts which better aid us in appreciating the beautiful and symmetrical personal character of Alexander Lyman Holley, and in valuing his varied and conscientious work as an engineer.

The resolution was seconded by Mr. Fritz, and adopted unanimously.

On motion the joint session adjourned.

MORNING SESSION.

November 2d, 1882.

The annual meeting of the American Society of Mechanical Engineers was called to order in the Turf Club Theater, New York City, at 10 A.M., on Thursday, November 2d, by the President.

The following members were in attendance:

A. Vanderbilt	New York City.
Frederick M. Wheeler	New York City.
Charles Sperry	Westbrook, Conn.
William K. Seaman	Scranton, Pa.
C. E. Billings	Hartford, Conn.
T. L. Churchill	Boston, Mass.
H. S. Hayward	Jersey City, N. J.
O. P. Remick	Newport, R. I.
W. Barnet Le Van	Philadelphia, Pa.
J. J. Illingworth	Utica, N. Y.
C. C. Collins	Erie, Pa.
E. H. Parks	Providence, R. I.
George H. Smith	Providence, R. I.
A. Faber Du Faur	New York City.
Moses G. Wilder	Philadelphia, Pa.
E. F. C. Davis	Pottsville, Pa.
George M. Bond	Hartford, Conn.
Charles P. Deane	Holyoke, Mass.
George H. Barrus	Boston, Mass.
S. W. Robinson	Columbus, O.
F. B. Allen	New York City.
A. C. Hobbs	Bridgeport, Conn.

W. F. Durfee	Bridgeport, Conn.
William H. Harrison	Braintree, Mass.
James E. Denton	Hoboken, N. J.
J. F. Holloway	Cleveland, O.
Thos. R. Almond	Brooklyn, N. Y.
Gaetano Lanza	Boston, Mass.
F. R. Hutton	New York City.
Albert Stearns	Brooklyn, N. Y.
Lewis F. Lyne	New York City.
Lycurgus B. Moore	New York City.
Jackson Bailey	New York City.
Horace B. Miller	New York City.
C. J. H. Woodbury	Boston, Mass.
William Cleveland Hicks	New York City.
William H. Weightman	New York City.
Alfred R. Wolff	New York City.
R. H. Thurston	Hoboken, N. J.
J. Sellers Bancroft	Philadelphia, Pa.
S. H. Finch	New York City.
William J. Baldwin	New York City.
Oberlin Smith	Bridgeton, N. J.
Thomas R. Pickering	Portland, Conn.
J. C. Bayles	New York City.
Alfred Colin	New York City.
A. Miller	New York City.
H. C. Jones	Wilmington, Del.
H. A. Hill	Boston, Mass.
William J. Root	Brooklyn, N. Y.
Thomas Whiteside Rae	New York City.
William P. Trowbridge	New York City.
Joshua Rose	New York City.
William E. Partridge	New York City.
W. G. Cartwright	Hoboken, N. J.
J. Burkitt Webb	Ithaca, N. Y.
C. Kirchoff, Jr.	New York City.
Thomas Egleston	New York City.

On motion of Mr. Durfee it was agreed to dispense with the reading of the minutes of the last meeting, and to accept them as recorded.

The President.—The first thing to be taken up in the order of business will be the counting of the ballots for new members. How will you have them counted?

Prof. J. Sweet.—I move that the chairman appoint tellers, and that the tellers report as soon as possible.

The motion being seconded and carried, the President appointed Mr. Franklin B. Allen as first teller, and requested him to select two gentlemen to assist him in this duty.

The President.—The next action in the order of business should be a report from the Council in regard to the general condition of the Society. A Council meeting was to have been held this morning; but the early meeting of the Society, and the fact that members do not come in promptly would prevent our having a quorum. I can say, however, all that need be said in the matter. The Society has increased in membership since the first of the year just closed, from 297 to 354, if we include those balloted for to-day. During the year the Secretary has issued Volume II. of the Transactions, and it has been sent out to members. The papers of the last meeting were to have been sent in by the printers to-day, and the Secretary expects them every moment. The report of the Treasurer lies before me, and I will ask the Secretary to read it.

The Secretary then read the Treasurer's report as follows:

TREASURER'S REPORT.

NEW YORK, November 1, 1882.

To the American Society of Mechanical Engineers:

GENTLEMEN:—I have the honor to submit the second annual report of the finances of the Society, which extends from my acceptance of the office of Treasurer on December 7, 1881, to the present date.

Receipts have been as follows:

Transfer from past Treasurer, December 7, 1881, in cash	$1,178 08
Transfer from past Treasurer, December 7, 1881, petty cash	25 00
Life membership	150 00
Initiation fees	445 00
Annual dues	2,624 13
Badges	404 54
Interest on United States Bonds	60 00
Sale United States Bonds face value $1,000 cost	1,138 75
Premium on ditto	61 25
Paper sales	9 15
Total	$6,095 90

Payments as follows:

Engraving	$358 12
Traveling	6 36
General expenses	648 25
Salary	1,696 97
Printing and stationery	1,887 39
Postage	417 23
Badges	1,074 00
Total	$6,088 32

thus leaving on hand a balance at this date in bank of $7.58.

In addition to the above cash receipts from the past Treasurer, there was also placed in my hands, as an invested fund of the Society, two 4 per cent. United States Government bonds of the face value of $1,000 each. All the payments made were upon the audit of the bills and vouchers by the Finance Committee according to the rules of the Society.

On account of accumulated indebtedness against the Society on August 7, and to the want of sufficient funds in bank at the time to pay these bills, I considered it to the interest of the Society to sell one of the United States Government bonds to procure the necessary funds to sustain the credit of the Society. This I did. From its disposal I received $1,200, being a premium of $61.25 above the cost. This leaves in my hands at this date but one of the above-mentioned United States Government bonds, and which is held as an invested fund.

There is at the present time due from membership $376.31, as follows:

For initiation fees	$30 00
For annual dues	285 45
For badges	60 86
Total	$376 31

There are in my hands at this time duly audited bills by the Finance Committee amounting to $57 for printing, which, for the want of ready funds, still remain unpaid. I am also informed that there is a bill amounting to $988 in the hands of the Secretary of this Society for printing, ready to be audited by the Finance Committee when the funds are available for its payment. There are in addition due the Secretary one month's salary for services for the month of October, as well as three months' clerk hire for the Treasurer, these amounting to $200.

It seems not to be well understood by some members of the Society that the annual dues are payable at the commencement of the Society's year, namely, in November, commencing the year, and it is probably for this reason that the dues of so many of the members remain unpaid, they supposing them payable at the end of the year. If this was clearly understood by all the membership the dues would undoubtedly be more promptly paid.

The total amount of receipts from all items of membership for the last year, if all accounts had been closed, would have been $3,692, and the total expenditures for the same period being

$6,088.32, shows an amount of $2,396.32 expended more than the total amount receivable from all sources of membership during the past year.

Respectfully submitted,
CHARLES W. COPELAND, *Treasurer.*

The President.—I would say in regard to this matter of finance, that it is the most critical matter which the Society will have to attend to during the coming two years. Our expenses have exceeded our current receipts. The fact is due partly to the expenditure which has been made in the publication of papers and partly to the circumstance that a good deal of the previous year's work was paid for during the past year.

Balancing accounts as well as I can, comparing the current receipts from membership dues with the necessary expenses, it looks as if they would just about balance, assuming that we print our transactions as we have done heretofore. The result has been this year the production of a volume of considerable size, and on the whole I think of considerable value to the members. But during the coming year it is proper that some course should be taken to limit expenditures, and at the last Council meeting a plan was talked over of making appropriations based upon the current receipts simply, and the receipts not of the current year but of the previous year. That is to say, our receipts last year were about $3,600, and during the coming year the idea would be to pay one-third of that amount to the Publication Committee, and limit the amount of expenditure to that sum. Then, basing our appropriations in that way and leaving a large margin for incidental expenses, it would place the Society in such shape that it never could become bankrupt. I imagine that when the newly-elected officers have taken their seats, their first duty will be to adjust some such plan and arrange with the Finance Committee for its adoption, so that no appropriations shall be made that are not fully within the line within which the Society is to work. I should say of my own judgment that the publication of papers during the coming year will be considerably restricted, and that we shall not issue as many papers as during the past. Incidental expenditures have been considerable, as they naturally would be in starting a new work like this; but how far they can be restricted in future it is impossible for me to say. I have no doubt, however, that if we find difficulty in doing the work we have to do with the funds coming in from dues, we shall find members willing

to make a little balance for us. Among the schemes in hand is one that the Publication Committee and the Finance Committee shall constitute themselves a committee of solicitation in the hope of getting a large publication fund. If any member has any suggestions to make in regard to the matter they can be presented here orally or sent in writing to the Council.

Reports from committees are in order. We have one very important committee to report this session. Is any member of the Committee on Gauges present?

A Member.—The report is prepared, but has not yet been submitted to the committee. They have called a meeting for this afternoon after the close of the afternoon session.

The President.—If it suits the gentleman, I will say then that the meeting of the Gauge Committee occurs at five o'clock, for the purpose of completing that committee's report, and we hope to have it before us at our next business meeting.

Is any report to be presented by the Committee on the Holley Memorial? Can Mr. Bayles tell us anything about that?

Mr. Bayles.—The committees of the three societies met last evening after the close of Dr. Raymond's lecture, and it was then announced unofficially, the Secretary not being present, that the subscriptions had somewhat exceeded $7,000 at that time—I believe about $7,500—and it was suggested to me that I had better mention in the meeting of this Society that the Treasurer would be very glad to receive small subscriptions, and that those who have held back, as many of us have, until gentlemen of wealth who desired to lead in this matter had made their subscriptions, can now make such contributions as they wish. Small subscriptions—of five dollars, or twenty-five dollars, or any other amount that pleases members—will be very acceptable. These subscriptions may be sent to Mr. Charles McDonald, 50 Wall Street, or to any member of the committee.

The President.—We have one or two amendments to the by-laws presented to be voted on at this meeting. We are ready to hear them and take action upon them.

The Secretary read the following amendment:

"*Resolved*, That Article XXVI. of the rules be amended so as to erase the word, 'Five members of the Council shall constitute a quorum, but,' and allow Article XXVI. to commence with the words: 'The Council may appoint,'" etc.

The Secretary.—I would ask that this be passed over to the fol-

lowing meeting, as I wish to submit a further amendment to this, due to some information I have received from a legal authority in regard to it. I was informed that by the law under which we are incorporated, the number of trustees, or the management, may not exceed thirteen. The object of the amendment just read was to bring our rules into strict conformity with the laws of the State, which say that a quorum shall be a majority of the governing body. Our rules prescribe that five shall be a quorum, and our governing body numbers seventeen. There is a lack of consistency here, and, of course, our rules ought to be in strict conformity with the laws of the State under which we are incorporated. I am also advised that our governing body may not, by the same law, exceed thirteen. It numbers seventeen. I learned this only yesterday, and I wish to modify the amendment so as to bring it into accord with the law on that point also. This can be done only by action of the council, so that I am not prepared to submit the amendment to-day.

Mr. Le Van.—Can it go over a year? According to our by-laws all amendments must be made a year in advance. Now the question arises, does not the amendment now proposed put us forward another year?

The President.—If not passed on at this meeting it goes over for another year.

Prof. Hutton.—I move that the matter be laid on the table, in order that the Secretary may present it to the council, so that he can bring it before the meeting, and that our By-Laws may be brought into conformity with the laws of the State.

Agreed to.

The Secretary.—The following amendment was offered by Mr. Bayles:

"Article XL. to read: 'The Society shall claim no exclusive copyright in papers read at its meetings, or in reports of discussions thereon, except in the matter of official publication with the Society's imprint as its transactions. The Secretary shall have sole possession of papers between the time of their acceptance by the Council and their reading, together with the drawings illustrating the same; and at the time of said reading he shall have printed copies for distribution to members present, and shall give the same to representatives of such newspapers as desire them for unofficial publication in whole or part. Copies of the drawings shall at the same time be furnished to journals which have previously made application for them, at the cost of making such copies; *Provided*, that the author of a paper shall in no case be deprived of his right to give copies of the same to any one he chooses, before it is read, or afterward; but if such paper is published unofficially prior to the meeting at which it is to be read, it

shall be considered as withdrawn by the author, and shall not be presented for reading or discussion as a paper of the Society.' "

The Secretary.—This was further amended at the same session by interpolating the words, "with the author's consent." Mr. Bayles also offered an amendment by substitution, as follows:

"Article XL. to read: 'The Society shall claim no exclusive copyright in papers read at the meetings, nor in reports of discussions, except in the matter of official publication, with the Society's imprint, as its transactions. The Secretary shall have sole possession of papers between the time of their acceptance by the Council and their reading, together with the drawings illustrating the same; and at the time of such reading, or as soon thereafter as practicable, he shall have printed copies of such papers, "subject to revision," with such illustrations as are needed for the transactions, for distribution to the members, and for the use of technical newspapers, American and foreign, which may desire to reprint them in whole or in part. The policy of the Society in this matter shall be to give papers read before it the widest currency possible, with a view to making the work of the Society known, encouraging mechanical progress, and extending the professional reputation of its members.' "

The President.—Is the seconder of the original motion present?

Mr. Durfee.—If this is the amendment offered at Altoona, I was the seconder. I accept the amendment.

The amendment was adopted.

The Secretary.—Mr. Le Van offered the following resolution:

"*Resolved*, That each paper intended for presentation and discussion at any meeting of this Society shall, if it pass the Council, be printed with suitable illustrations, 'subject to revision,' and mailed to each member at least six weeks prior to the meeting for which it is intended, and shall also be distributed at said meeting, at which it shall be read by title *only*. Discussions thereon shall then be in order; discussions to be stenographically reported and appended to the revised copy of the paper, which revised copy, with the report of the discussion, shall constitute the authorized edition of the paper, and shall be part of the published *transactions* of the society."

Mr. Bayles.—I merely call attention to the fact that this amendment is in conflict with the one passed which provides that the Secretary shall, *if he can*, print papers before the meeting, or as soon thereafter as possible. I think the resolution just passed anticipates this entirely.

Mr. Le Van.—My resolution says they *must* be printed. The other does not. The great trouble is that no one can carry the paper in his memory after merely hearing it read, and discuss it properly. My object in having them printed in advance was that any one could discuss them. The discussion is the kernel.

Mr. Durfee.—In order to make such a proposition feasible, you will have to pass a resolution compelling every member to print his paper.

Mr. Weightman.—Does this amendment provide for discussion by the Publication Committee as to whether a paper shall be read or published?

The President.—Yes; a resolution of the Council covers that.

Mr. Weightman.—Should not the Publication Committee be brought in there? Because all papers are referred to them first, and from them they go to the Council.

The President.—The Society, however, knows nothing about the Publication Committee. It is a committee formed by the Council to further its own work.

Mr. Rae.—I can simply reiterate the objection which Mr. Bayles makes, that this would have excluded almost all our papers. The experience has been that papers are not submitted until within a few days of the meeting. Our membership is composed of busy men who cannot say with any positiveness that they will be able to present a paper, and all are very chary about saying that they will furnish one at a specific time. Such a rule as this would have excluded nine-tenths of the papers which have been read. I get a conditional promise, and perhaps a day or two in advance of the meeting a paper will be submitted. I would say that only one paper would be brought forward at this meeting if such a rule as Mr. Le Van's amendment contemplates were in force.

Mr. Le Van.—Would it not be better for one good paper to be read than for several to be read which we are not able to discuss?

Mr. Durfee.—I think Mr. Le Van's objection is amply covered by the practice the Society has thus far followed: that is, taking up the papers read at previous meetings and re-discussing them. I think in the programme of this very meeting there is some provision of the kind. Any gentleman who wishes to prepare himself for discussing any particular point has ample opportunity to do so.

Mr. Le Van.—That is like reading last month's news.

Mr. Weightman.—I believe I understood Mr. Le Van to say that the very point of his amendment was that these papers would not be read, but only the discussion would take place. I think the gentleman will find that very few papers will be read outside the meeting. I would like to ask how many of the published papers he or any other member has read outside the meeting at which they were placed before the Society. I have not read one straight through,

and I think the majority of the members will say about the same The mere hearing of the paper read will start a little discussion, while if it is only placed before the Society to read, I am afraid it will fall to the ground.

Mr. Alden.—I would like to ask if six weeks is not a longer time than is necessary in order to have the papers in the hands of the members. I suppose this contemplates that they should be in the hands of members and studied before they are discussed here. A regulation to send them to the committee at least one week before the meeting would not seem so severe.

Mr. Le Van.—My object in stating six weeks is merely to give the Secretary time.

The President.—In answer to the gentleman's question, I would say that, observing the working of the thing, I should conclude that we shall be compelled to allow the members to do about as they do at present—to get their papers in if they are ready, and if not, to let them go over. The drawing of a line is likely to produce some embarrassment. The law of the survival of the fittest would lead no doubt to the presentation of very valuable papers ultimately and to the killing out of those which are not of so much value. I should only say, as a matter of observation simply, that it would to some extent interfere with the work of publication.

A Member.—I think that the most valuable discussions coming before the Society are the impromptu discussions which take place after the paper is read. If a paper is to be discussed after two or three months, it will lose a great deal of its interest.

The amendment proposed by Mr. Le Van was lost.

Mr. Le Van.—I also asked to change the time of meeting. In the first place every meeting we have had in November, except this one, has been held in rainy weather. It is not cold enough to have a fire here and it is too cold to sit without an overcoat. I do not think the health of the members should be sacrificed in order to have a meeting just on the first or second of November for some reason I cannot account for.

The Secretary.—Such a recommendation as Mr. Le Van mentions was brought forward. But the fixing of the time of the annual meeting is given by the rules entirely to the Council. The matter does not come before the Society at all, and the Council has so far declined to make any change.

The President.—The rule in regard to the matter reads: "The annual meeting of the Society shall be held in the City of New

York on the first Thursday in November, at which a report of the proceedings of the Society and an abstract of the accounts shall be furnished by the Council; the Council may change the time of the annual meeting, and shall in that case give six months' notice to members and associates."

The proper form of amendment here would be one which should take from the Council this authority to change the time of the annual meeting, or should simply take the form of a recommendation to the Council that it be changed. In the first case it would have to go through this form, and should have been proposed in this form. In the second case, as a mere recommendation, it can come in now or at any time.

Mr. Le Van.—I would ask then that it be made a recommendation to the Council to have it changed.

The President.—Cannot Mr. Le Van put that resolution in form?

Mr. Le Van.—Not in any better form than I put it last year.

The Secretary.—There is no such resolution on the minutes, and none came formally before the Society to my knowledge.

Mr. Weightman.—Is there any necessity for such a resolution? I think the Council will take note of it at the mere request of one member.

The President.—In the absence of any resolution of course debate is not in order. Is there any other business of this character offered, or any general business at all? Is any report to be presented by the Committee on Tests of Iron and Steel? That committee is still in existence, and I understand that a meeting of it is set for to-day.

Mr. Woodbury.—Dr. Egleston notified me yesterday of a meeting of the committee this afternoon, and as he does not seem to be here this morning I take the responsibility of assuming that he will present something on behalf of the committee later during this meeting.

The President.—The next matter in the order of business will be the discussion of earlier papers.

Mr. Wiley.—I simply want to bring before the meeting the fact that we ought to nominate our officers in a different way from what we do now. I do not know just how this matter should be brought up, but I am sure of the fact that the present method ought to be changed.

The President.—It should be carefully considered, and a resolution written out and presented.

Mr. Weightman.—I was requested by the Treasurer to suggest some amendments, and I would move that a special committee be appointed to revise our By-Laws, and to report at our next annual meeting, or, if possible, to report at our next regular meeting, so that such suggestions could be adopted at the annual meeting. I would make the motion that a special committee on by-laws be appointed.

The President.—Would it suit the gentleman as well to put his motion in this form, that a committee be appointed by the new Council? It would be somewhat ungracious for the outgoing Council to appoint committees for the new Council.

Mr. Weightman.—I would put it in that form, or for the Chairman to appoint such a committee.

Mr. Durfee.—I second the motion, and for this reason: I am profoundly of the opinion that we are using up at these annual and other meetings altogether too much time in discussing amendments which are of comparatively little value when viewed in their relation to the real work of the Society, and if there is any means by which we can have some laws that resemble those of the Medes and Persians, that may not be altered, I hope that a resolution leading to such a result will be passed.

Mr. Bayles.—I would like to ask whether the appointment of this committee cuts off the right of the members to amend the rules.

The President.—The amendments just passed upon of course are gone by. Future amendments will be referred to such committee, I should say, if it were formed.

Mr. Woodbury.—The epitaph which should be put on the gravestone of many a disorganized society would be, "Strangled by its own by-laws." While there are many items in our constitution and by-laws which might be more convenient to individual members here and there, yet, as a whole, I deprecate the idea of devoting so much time to alterations which are little more than verbal in their character. The by-laws were very carefully prepared in the first place by persons conversant with the working of similar societies, and who had had long experience in affairs; and while it may be necessary to make changes now and then for the most harmonious and efficient operation of this Society, it seems to me that it would be a retrogression and not a step forward to endeavor to reorganize or to give a committee power which would look to that result in the way of altering our constitution and by-laws. We

come here for professional purposes, and not to quibble over matters of law.

Mr. Weightman.—It was just for that purpose that I made this motion, so that such discussions should take place in the special committee. So far as our by-laws being to a certain extent a matter of death to us, there is one point brought up here, and that is that in our money matters there is constant complaint now that we are running behind. The Treasurer has complained of one point in reference to our by-laws, and that is that nobody is responsible for the money spent. Article XXVII. says that no bill shall be paid for the Society until it has been certified to by the person authorized to contract it, and audited by the Committee on Finance. Now he wishes to know what power there is in the Committee on Finance to audit a bill after it has been contracted by the person spending the money. He being the person authorized to contract the bill, the Finance Committee must necessarily pay it. The auditing of it, the Treasurer claims, is a farce, and he can see no method of governing expenditure so as to keep it in due bounds and within our receipts. Those are points which were taken from the Treasurer at his request. It was at his request that I mentioned these matters. I thought it would cover it better by referring the whole matter to the Committee on By-Laws, when the discussion could take place outside our meetings.

Mr. Rose.—The object of the first mover (Mr. Wiley) was to give the members of the Society some voice in the election of its officers. As we are at present constituted, we are presented with just enough names to fill just so many offices, and therefore the members of the Society have no voice whatever, except so far as they are represented by the Council, in the choice of officers.

The resolution proposed by Mr. Weightman was agreed to.

The President.—If there is nothing further to be offered in regard to the papers presented at the last meeting, we will proceed to the reading of the papers offered for this meeting. We have a paper by Mr. Seaman on "The Rail Cambering Arrangement of the Lackawanna Coal and Iron Company."

Mr. Seaman read his paper, and discussion followed.

After the discussion of Mr. Seaman's paper, Mr. Hayward read a paper entitled "An Adjustable Cut off for Steam Engines," and discussion followed.

The tellers having opened and counted the ballots, made a

report, announcing the election of the following gentlemen as members of the Society in their respective grades:

HONORARY MEMBERS.

DANIEL K. CLARK, M. I. C. E., London, England.
RUDOLPH CLAUSIUS, Bonn, Prussia.
PETER COOPER, D. C. L., New York City.
O. HALLAUER, Sec. Ing. Civils de France, Munster, Alsace.
G A. HIRN, Correspondent de l'Institut de France, Associé des Académies de Belgique, de Suède, &c., &c., Colmar, Alsace.
FRANCIS REULEAUX, Berlin, Prussia.
SIR EDWIN J. REED, K. C. B., M. P., London, England.
HENRI SCHNEIDER, Le Creusot, France.
C. WILLIAM SIEMENS, D. C. L., F. R. S., &c., London, England.
HENRI TRESCA, Membre de l'Institut, President Honoraire de la Société des Ingenieurs Civils, Paris, France.

PROMOTIONS.

WILLIAM K. SEAMAN, Associate A. S. M. E., Scranton, Pa.
CHARLES C. WORTHINGTON, Associate A. S. M. E., New York City.

MEMBERS.

WILLIAM J. BALDWIN, Superintending Engineer Nason M'f'g Co., 71 Beekman Street, New York City.
THEODORE BERGNER, 424 Walnut Street, Philadelphia, Pa.
M. C. BULLOCK, 86 Market Street, Chicago, Ill.
THEODORE COOPER, 35 Broadway, New York City.
S. ASHTON HAND, Toughkenamon, Chester Co., Pa.
CHARLES KIRCHHOFF, JR., 27 Park Place, New York City.
GAETANO LANZA, Mass. Institute of Technology, Boston, Mass.
JOHN W. MOORE, Chief Engineer, U. S. N., Champlain, Clinton Co., N. Y.
EDWARD S. RENWICK, 19 Park Place, New York City.
COLEMAN SELLERS, JR., 332 N. 33d Street, Philadelphia, Pa.
HENRY R. TOWNE, Stamford, Conn.
DAVID TOWNSEND, Bush Hill Iron Works, Philadelphia, Pa.
PROF. JOHN BURKITT WEBB, Ithaca, N. Y.
B. H. BARTOL, 1,909 Spruce Street, Philadelphia, Pa.
HENRY LEON BINSSE, 40 W. 19th Street, New York City.
H. M. BYLLESBY, 65 Fifth Avenue, New York City.
JOHN W. CARRINGTON, 579 Classon Avenue, Brooklyn, N. Y.
CHARLES L. CLARKE, 65 Fifth Avenue, New York City.
VINCENT G. HAZARD, The Pusey & Jones Co., Wilmington, Del.
WILLIAM F. MATTES, Scranton, Pa.
THOMAS R. MORGAN, Alliance, Ohio.
HENRY G. MORRIS, Philadelphia, Pa.
A. J. PITKIN, Schenectady Locomotive Works, Schenectady, N. Y.
STEPHEN NICHOLSON, Providence, R. I.
WILLIAM H. PATTON, Virginia City, Nev.
IRVING M. SCOTT, San Francisco, Cal.
EDWARD WESTON, Newark, N. J.

JOHN R. ABBE, Manchester, N. H.
MOSES G. FARMER, Newport, R. I.
CHARLES C. ABBE, South Windham, Conn.
GEORGE W. BIGELOW, New Haven, Conn.
WILMER G. CARTWRIGHT, Stevens Institute, Hoboken, N. J.
J. H. MCEWEN, Supt. McEwen Bros. Mach. and Eng. Works, Wellsville, Pa.
F. A. HALSEY, 249 Broadway, New York.
WILLIAM LEONARD NICOLL, Navy Department, Washington, D. C.
JOHN WALKER, Walker Manufacturing Co., Cleveland, Ohio.
WM. C. WILLIAMSON, Philadelphia, Pa.

ASSOCIATE.

A. ALLER, 109 Liberty Street, New York.

JUNIOR.

SAMUEL HIGGINS, Susquehanna, Pa.

The tellers also reported the election of the following officers for the terms specified in the constitution, as the result of the votes of the Society.

PRESIDENT,
E. D. LEAVITT, JR.

VICE-PRESIDENTS,
JOHN FRITZ,
HENRY MORTON,
WILLIAM METCALF.

MANAGERS,
ROBERT W. HUNT,
CHARLES T. PORTER,
C. J. H. WOODBURY.

TREASURER.
CHARLES W. COPELAND.

After presentation of the tellers' report, Mr. F. B. Allen read a paper on "The Protective Value of Boiler Inspection," and discussion followed.

After the discussion, the meeting adjourned till 2.30 P.M.

AFTERNOON SESSION.

The meeting was called to order at 2.30 P.M.

The President read his annual address.

The President.—There is now an opportunity for any business if any is to be presented this afternoon. If not we will proceed to the reading of papers. Is Professor Robinson's paper ready?

Professor Robinson.—I have brought in two small items at this meeting for the consideration of the Society, and I hope not to take much of the time of the Society with them. One is in regard to the back pressure on valves. The other is a supplement to the paper I read at the Philadelphia meeting on "Pumping Engines." The matter I have to present on the subject of valves was experimentally obtained by a student in the mechanical laboratory of the Ohio State University about a year and a half ago. The question is often raised, I presume, by members of the Society in practice what pressure to allow for a slide valve in determining the resistance of that slide valve. We are at first, perhaps, inclined to take the whole area of the slide valve, multiply that by the pressure in the steam-chest, and call that the pressure of the valve in its seat. I directed these experiments for the purpose of throwing some light on the question.

Professor Robinson then proceeded to explain his drawings.

At the conclusion of this paper, arose

The President.—While we are waiting for the next paper, I have an explanation which I wish to make at the request of Colonel Laidley. Colonel Laidley is the officer of the army to whom we are indebted, I presume, for the bringing up of the form of testing machine finally adopted by the United States Board and built and put down at Watertown. In debate, I think at the last meeting, it was stated that the contract made for that board had been annulled before the board itself had taken action. He says that this was an error; that it became necessary that the board should either have the machine that had been contracted for or lose the money appropriated for it, or annul the contract. The board chose the latter alternative. "Had it not done so, the contract would not have been annulled," he continues, "and I should have had at this moment the machine." He goes on to express his regret at that action. He desired a correction of the statement to be made.

A paper by Mr. Hill on the "Difficulties of Road Locomotion, their Cause and Cure," was read by the Secretary.

Mr. Oberlin Smith read a paper on the "Systematic Preservation of Drawings."

The meeting then adjourned till the following day at 7.30 P.M.

In the evening was held the subscription dinner, attended by a large delegation of the membership. It was held in a room adjoining the headquarters, and several ladies were present. It was a very pleasant reunion.

Friday, November 3d, was spent very enjoyably by the members of the Society in an excursion upon New York Bay, stopping at various points of interest. Leaving the foot of Cortlandt Street pier in a propeller tendered to the Society by the courtesy of the Pennsylvania Railroad, the Hudson River tunnel was first visited on the Jersey City side. Members inspected the compressing plant and could descend to the air-lock in the finished work.

Leaving the tunnel, the excursionists steamed around the Battery, and after luncheon, served in the cabin of the boat, were landed at the Brooklyn tower of the East River bridge. Under the direction of one of the engineers, the society visited the massive anchorage and engine chambers in the approach, and then passed to the roadway to cross the bridge. The somewhat perilous passage was made on the plank foot-way, and the propeller was found at the New York tower. After a visit to the Morgan Iron Works at East 9th Street, the members returned to Pier 19, and were escorted to the office of the New York Steam Company, and listened to a short description of its methods by Mr. Chas. E. Emery. Thence they visited the boiler house of the company in Greenwich Street, and saw the successive tiers of boilers, the arrangements for coal, for draft and for return water. After separating at this point, the members re-assembled at the Turf Club Theater in the evening.

The meeting was called to order at 7.30 P.M.

Prof. Gaetano Lanza read a paper entitled "An Account of Certain Tests of the Strength and Stiffness of Large Spruce Beams," and discussion followed. His paper was illustrated by photographs thrown on a screen by a projection lantern.

After the discussion, the report of the Committee on Gauges was called for and read by Mr. Bancroft, as follows :

AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

Your Committee on Standards and Gauges have to report that they have examined the Rogers-Bond Comparator in use by the Pratt & Whitney Company at Hartford, Conn., together with gauges for end measure produced by the use of this machine.

This apparatus is used, first to compare line measures of length with attested copies of the standard bars of England and the United States; second, to subdivide these line measures into their aliquot parts and to investigate and determine the errors, if any, of these subdivisions; and, third, to reduce these line measures to end measures for practical use in the shops.

A paper read by Professor W. A. Rogers before the American Academy of Arts and Sciences, April 14, 1880, on "The Present State of the Question of Standards of Lengths," and a paper read by Mr. George M. Bond before this Society at its regular meeting in Hartford, 1881, will give all the needed information on the subject of standards of line measures.

The comparator is provided with two microscopes, their magnifying power being about 150 diameters, each having a micrometer eye piece the divisions of which represent about one sixty-thousandth of an inch, and in reading, these divisions are usually subdivided by the eye into tenths, in every case at least three readings being taken, and the mean of the three is used in calculating the result.

The microscopes are mounted upon a carriage which slides freely upon two cylindrical guides, which are heavy tubes of hard tool steel, carefully ground true and cylindrical. These are supported at their ends in bearings formed in the heavy cast-iron base of the machine. Counter-weight levers are applied under these tubes at about one-quarter the total length from each end, to overcome the flexure arising from their own weight and that of the carriage and stops. These stops are arranged so as to be clamped firmly to the guides at any desired distance apart; they serve to limit the motion of the microscope plate or carriage when brought in contact with either stop. The carriage is moved up against the stops by a rack and pinion which is provided for the purpose, the rack being secured to the bed of the comparator between and independent of the guide bars. The abutting surfaces of the carriage and stops are hardened steel, those on the carriage being spherical, while those on the stops are flat, and each stop is provided with an electro-magnet that serves to hold the carriage firmly against the stop so as to prevent its settling back during an observation.

On one side of the comparator is a table provided with rapid vertical and lateral adjustments and with a traverse parallel with the motion of the microscope plate of about 45 inches; on top of this table is an adjustable plate on which the standard bars are laid to be compared. This plate is provided with fine adjustments for parallelism, focus and end position, and several line-measure standards may thus be compared at once under the microscopes without handling the bars. This is an important feature, as it will be evident that errors due to variations of temperature resulting from handling or from any other cause, must be carefully guarded against. On

the opposite side of the comparator is a fixed table or projecting ledge forming part of the base on which this adjustable plate may be placed, so that standard bars may be investigated on either side of the machine. For regular work this place is occupied by the caliper for reducing from line to end measure. The microscopes are mounted upon the carriage in such a manner that they may be used both on one side or one on each side of the carriage, at variable distances according to the character of the work to be examined.

The comparator is firmly supported on solid brick piers capped with stone, and the movable table, having a traverse of about 45 inches, referred to above, is on an entirely separate foundation, to avoid all disturbance of the microscopes that might arise from moving the table.

Subdivisions of a standard bar may be compared by placing the microscopes say twelve inches apart, if the subdivisions under investigation are feet; the variation being measured or read by means of the micrometer eye-piece. The standard is then moved under the fixed microscopes so as to compare each separate twelve inches successively, their relation being thus determined.

Another method is to fix the stops so that the microscope carriage will have a movement of as near the length of the subdivisions to be examined as may be convenient; in this case only one microscope is used, the carriage moving a fixed distance between the two stops, the subdivisions of the standard being thus compared with a constant quantity, and their relation consequently determined.

Line-measure standards may be compared on this machine:

(*a.*) By referring the standards to a fixed distance between two stops.

(*b.*) By bringing the defining lines under two fixed microscopes placed the same distance apart as the length of the standards to be compared.

(*c.*) By placing two standards to be compared side by side, and placing one microscope over each bar, the carriage being then moved the length of the bars, and the relative length of the standards readily determined.

(*d.*) By placing one standard on one side of the line of motion of the microscope carriage, and one on the opposite side, using one microscope for each bar; by reversing the position of the bars, the mean difference may be found.

(*e.*) By comparing standards by the use of two microscopes placed horizontally, and at a fixed distance apart, so that stand-

ards can be compared in the same position, and under the same conditions that comparisons are made at the United States Coast Survey Department at Washington.

The microscope carriage should move in an absolutely straight line, and the cylindrical guides give perhaps the closest approximation to this condition. Errors, however, will exist; and the correction for possible horizontal curvature of the guide bars is found by comparing a standard with a fixed distance between the stops, first on the left-hand side of the microscope carriage, and afterward on the right-hand side, under the same condition in both cases of temperature, and points of support of the standard and focus; the face of the bar must in both cases be maintained in the same horizontal plane, to avoid errors due to vertical flexure of the guides. The difference of the two comparisons with the fixed or constant distance, furnishing data for calculating the radius of curvature and the position of the center, that is, on which side it is located, and hence determining the sign of the proper correction, whether it be plus or minus, should the amount be appreciable.

The vertical curvature or flexure may be determined in the same way, using the standard bar placed at varying heights, and comparing it with the constant distance moved by the microscope carriage, the microscope and bar being kept always in the same vertical plane to eliminate errors of horizontal curvature.

In transferring from line to end measure, as the two microscopes do not move in the same vertical plane, correction for horizontal curvature, if of appreciable amount, must be applied with the proper sign as remarked above, as in such case one microscope evidently would move a distance differing from that of the other by the difference of the lengths of the subtended chords.

Errors due to vertical curvature or deflection of the guide bars, may be practically eliminated by taking care to keep the surfaces on which the lines to be observed by the microscope are ruled in precisely the same horizontal plane.

The caliper attachment to the comparator provides means for reducing line measure to the practical form of end measure, and consists of a fixed stop and a movable plunger, cylindrical in form, sliding in well-fitted bearings and having a traverse of about six inches. The abutting faces of the plunger and fixed stop are of hardened steel three-eighths of an inch in diameter, and are ground to true plane surfaces which are perpendicular to the line of motion of the plunger.

The plunger is pressed against the fixed stop, and also against anything held between the surfaces of the plunger and fixed stop, by a rod which compresses a spiral spring within the plunger. This rod is clamped to place so as to hold the pressure of the spring constant while the observation is being made, the amount of compression of the spring being made approximately equal in each case. This simple contrivance dispenses with the need of the gravity piece used by Whitworth. No great care need be taken as to the amount of compression of the spring, as no perceptible difference is shown under the microscope when the spring is compressed an amount varying from one-quarter of an inch to two and one-half inches. The line upon the plate on the plunger being about 1-30.000th of an inch in width, and the line in the micrometer eye-piece being in exact coincidence with the ruled line upon the plate, no change of relative position was perceptible during a continued observation through the microscope magnifying about 150 diameters, while the spring was subjected to varying compression within the above limits. The error due to flexure of the end measures is not appreciable in pieces up to six inches in length, but standard bars of twelve inches and longer require supports, and great care must then be taken to have the bar to be measured parallel to the line of motion of the plunger and microscope carriage.

This caliper is used with two microscopes, one of which is over a finely ruled standard bar, and the other over a finely-ruled plate which is attached to the plunger, care being taken to have this plate over its entire line of motion in the same horizontal plane as the surface of the standard ruled bar. The faces of the caliper are brought in contact by the rod and spiral spring, and the microscope adjusted until it bisects the line on the plate attached to the plunger. The other microscope is set so as to bisect the initial line on the standard ruled bar, both microscopes being firmly attached to the carriage; the plunger is now drawn back, the piece to be tested put between the faces of the caliper, and the plunger forced up until the spiral spring is compressed about the same amount as before. The carriage is now moved until the line on the plate is again bisected by its microscope, and the microscope over the standard bar by the aid of the micrometer, determines the exact length of the piece in terms of the subdivision on the ruled standard. This operation can be performed very rapidly, and with uniform results. One accustomed to the use of the micrometer will readily measure within one divis-

ion. A test to determine the accuracy of setting to a single line on the ruled bar made by six members of this committee, most of whom were quite inexperienced in the use of the microscope, showed between the highest and lowest of eighteen readings a difference of 5.5 divisions, a quantity less than 1-10,000th of an inch, while the average of the eighteen readings differed from the average readings of Mr. Bond by four-tenths of one division, or about 1-150,000th of an inch.

The end-measure pieces which your committee were shown at the works of the Pratt & Whitney Company, were stated to be correct within 1-50,000th of an inch; and perhaps the severest practical test was made by laying a number of these pieces in a groove planed in a massive block of cast iron, one piece being clamped down to form an end stop, and when the pieces laid down reached the length of twelve inches, another piece was clamped down. A quarter-inch piece was used as a try piece, and was held by a piece of wood inserted in a small hole passing through the piece; the end stops were adjusted until this try piece would just move easily—almost by its own weight. These pieces were then removed, and others, which had been laid on this cast-iron block so that they might all have the same temperature, were substituted, care being taken not to disturb the end stops; some twelve different sets were tried in this way, the same quarter-inch piece being used as a gauge, and these twelve sets were practically uniform in length, with one exception. In this case the quarter-inch piece was quite loose, and accordingly the end-measure pieces composing this set were all carefully measured on the comparator, as well as a set that had stood the test. The difference in length between the two sets, one composed of nine pieces, and the other of seven, being less than 1-10,000th of an inch, and one piece of the set composed of seven pieces was found to be 1-30,000th of an inch short, being exactly one-half the total error of the entire seven, as compared with the standard bar, and this was found to be one that had been condemned on account of a defect in the end surface.

Dividing the total difference by the number of pieces in the set, the difference noted above, of 1-10,000th of an inch between the total errors of the two sets referred to, shows an average difference for each piece of the first set, as compared to the length of the second set, of about 1-75,000th of an inch, and about 1-105,000th of an inch as compared with the subdivisions upon the standard bar, to which they were referred.

The end-measure pieces being all referred to lines ruled upon a hardened steel bar, and in a manner which reduces possible error to a minimum, the liability of a deterioration of the standard is eliminated; error would certainly result were they all compared with a standard end-measure test piece, the use of which, however slight, would be attended with more or less wear, and the original size thus lost; this *ruled bar* being preserved, the *originals* may be duplicated at any time. As the standard ruled bar is not handled or touched in any way during the process of measuring, the only risk of change would seem to be that due to internal strains in the standard itself. This point will require close investigation and comparison with other standards, to determine the stability of the hardened bar. This standard has been submitted to a process of annealing, at a temperature above any ordinary atmospheric heat due to climate, and this annealing is believed to eliminate the risks of after changes. A recent examination of this standard, which was so treated two years ago, shows no appreciable change.

Two adjoining sides of the end-measure pieces are first ground by special machinery to plane surfaces, which are perpendicular to each other, and the end surfaces are afterwards ground to true planes parallel with each other and at right angles with these side planes, by the use of a fixture which consists of a block having a slot through its center, the sides of which are exactly perpendicular to the base of the block. The block slides over a plane surface in the center of which is a copper plug charged with emery or diamond dust. The end-measure piece is secured in this slot and passed over the copper lap until the end is reduced to a polished plane surface; the piece is then reversed and the other end ground in like manner, careful measurements being made from time to time as the piece is gradually reduced in length, great care being taken to have the temperature correspond with that of the ruled bar. The test of these end measures in the groove in the block of cast iron above referred to shows the accuracy of this method of manufacture, as any want of parallelism in any of the ends would seriously affect the total length of the set.

Between and below the jaws of the caliper is a small table, which can be adjusted vertically for the purpose of calipering cylinders; the table is adjusted so as to bring the center of the cylinder to be measured to about the same height as that of the plunger, the axis of the cylinder being horizontal; the plunger is then pushed against the cylinder by means of the rod and spiral spring above

described. The pressure of this spring is sufficient to move the cylinder on the table until its sides are tangent to the plane surfaces on the plunger and fixed stop; by moving the cylinder back and forth it can be tested for parallelism, and by turning it, the plunger being in each case released and brought into contact again, it can be tested for rotundity, the whole operation requiring but a few moments.

The personal error in reading by microscope—that is, the variations different individuals would make in reading the intersection of the lines by the micrometer—is eliminated by the process of measuring, the microscope being in each case set to the zero on the ruled bar when the caliper faces are in contact, and also to the proper line when the object to be measured is between the jaws of the caliper; and hence any individual difference there may be in setting will be the same for the readings at each point, *i. e.*, at zero and at the position due to the length of the measured piece; and the difference between these two readings gives the length of the piece in terms of the standard bar. As the standard bar used by the Pratt & Whitney Co. for all measurements of four inches and under is of the same material as the end-measure pieces and plug gauges, no correction for temperature is required, the only precaution being that the piece to be measured shall be at the same temperature as the standard bar, which is readily accomplished by keeping them together for a few hours before measuring.

CONCLUSION.

The completion of the Rogers-Bond comparator marks a long stride in advance over any method hitherto in use for comparison and subdivision of line-measure standards, combining, as it does, all the approved methods of former observers with others original with the designers. Comparisons can thus be checked thoroughly by different systems, so that the final result of the series may be relied on as being much nearer absolute accuracy than any hitherto produced.

The calipering attachment to the comparator deserves special commendation, being simple in the extreme, and solving completely the problem of end measurements within the limit of accuracy attainable in line reading, by means of the microscope with the micrometer eye-piece. The standard to which the end measurements are referred is not touched, and each measurement is referred back to the same zero, so that error from end wear does not

enter into the problem. This attachment is in advance of all hitherto known methods of comparing end measures, either with other end measures or with line standards, both as to rapidity of manipulation and accuracy of its readings. The strong point in its construction being that it refers all end measures to a carefully divided and investigated standard bar, which is not touched during its use, and cannot be in the slightest degree injured by this service, thus giving convincing assurance that the measures and gauges produced by its use will be accurate and interchangeable.

In the opinion of this committee, the degree of accuracy already attained is such that no future improvements can occasion changes sufficiently great to affect the practical usefulness of the magnitudes here determined, or the interchangeability of structures based upon them with those involving further refinements.

Professor W. A. Rogers and Mr. George M. Bond are unquestionably entitled to great credit for the admirable manner in which they have solved the problem of exact and uniform measurement, while the enterprise of the Pratt & Whitney Co., in bringing the whole matter into practical shape, is deserving of the thanks of the engineering community.

J. Sellers Bancroft,
Secretary of the Committee.

Henry Morton, *President.*
S. W. Robinson.
Oberlin Smith.
E. H. Parks.
Ambrose Swasey.
Chas. T. Porter.
Alfred Betts.
George R. Stetson.

The President.—Is there any discussion on this report?

Mr. Miller.—I move that the report be accepted with thanks, and ordered to be printed.

Agreed to.

The report of the Committee on Tests of Iron, Steel, and other Metals, was read by Professor Egleston, as follows:

"The Committee on Tests of the American Society of Mechanical Engineers beg respectfully to report that they printed and sent

out 3,750 copies of the memorial which was adopted at the Philadelphia meeting, to the colleges and technical schools of the United States, to the iron and steel manufacturers, to the members of the American Institute of Mining Engineers, the American Society of Civil Engineers, and the American Society of Mechanical Engineers, and to the mill insurance companies of the New England States.

"Up to June 1st, 1,500 signatures, with the profession and addresses of the signers attached, had been received to the memorial. Copies of all of them were sent to the Hon. J. M. Campbell, Chairman of the Committee on Manufactures of the House of Representatives. The originals it was thought best to retain for future use, and they are now in the possession of your committee. It is believed that many signatures to the memorial were sent independently, and of these no copies have been sent to the committee. At the request of the Committee on Manufactures, every member of both Houses of Congress was furnished with a copy of the discussion on tests at the Philadelphia meeting.

"Your Committee also issued two circulars, which were sent with the memorials. One was sent to colleges and technical schools, asking their Faculties to send to the Hon. J. M. Campbell, at Washington, resolutions indorsing this memorial. The other requested those to whom it was sent personally to urge the support of the bill upon the Representatives from their district, and Senators from their State. A copy of each of these circulars is appended to this report.

"The committee had several interviews with Hon. J. M. Campbell, and with a number of other members of the House and Senate, and received from them the assurance that if the bill H. R. 4,726 did not pass Congress at the session of last spring, they would do their utmost to have it pass during the coming session.

"Your committee believes that the vigorous efforts made by the Society had a great deal to do with the passage of the appropriation of $10,000 for the use of the testing machine at Watertown.

"In the judgment of this committee, it seems worth while that the efforts of the Society in this direction should be continued during the coming year."

Appended are copies of the circulars issued by the committee:

AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

COMMITTEE ON TESTS.

NEW YORK, *May 22d*, 1882.

GENTLEMEN:

A bill proposed by the American Society of Civil Engineers, in conjunction with members of the American Society of Mechanical Engineers and of the American Institute of Mining Engineers, for the appointment of a commission to test metals and materials used in construction, and numbered H. R., 4,726, has been introduced into the House of Representatives, and unanimously reported to the House for passage by the Committee on Manufactures, of which Hon. J. M. Campbell, of Pennsylvania, is Chairman.

We are informed that, in order to have this bill become a law, interest in it must be shown, and it must be made evident that those interested in education, men of science, engineers, and others feel the need of such a commission. We therefore beg to ask you that the Faculty of your Institution will pass resolutions in favor of such a measure and forward the same to the Chairman of this Committee, to be sent to Washington with the least possible delay. Also, that you will use what influence you are able to command to induce Members of Congress to favor the creation of the commission.

In view of the magnificent industrial development of this country in the past, as well as its present prosperity, so much of which is due to the scientific knowledge and practical skill of our constructive engineers, the working capacity of whom can be so greatly augmented by a knowledge of facts, obtainable in the manner above mentioned, at a much less cost than by imperfect individual research, the committee request your assistance in this matter.

T. EGLESTON, *Chairman*,
School of Mines, E. 49th Street, N. Y.
E. D. LEAVITT, JR., *Cambridgeport, Mass.*
W. METCALF,
Miller, Metcalf & Parkin, Pittsburg, Pa.
OBERLIN SMITH, *Bridgeton, New Jersey.*
C. J. H. WOODBURY,
13 *Devonshire Street, Boston, Mass.*

AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

COMMITTEE ON TESTS.

NEW YORK, *May* 22, 1882.

DEAR SIR:

The bill for Testing Metals and Constructive Materials has been unanimously passed by the Committee on Manufactures, at Washington, and will soon be put on its passage in the House of Representatives. A vigorous opposition to it has been developed. The Committee of this Society is urged, by the Hon. J. M. Campbell, to secure influence in favor of the bill from as many quarters as possible. At his suggestion, you are earnestly urged to write *yourself*, *at once*, and to get others interested in the bill to write to both the Representatives from your District, and the Senators from your State, urging the passage of the bill as a measure likely to promote the welfare and interest of the United States.

A special edition of the debate at the late meeting of the Society in Philadelphia, is now being prepared for the use of Members of Congress.

Yours, truly,

T. EGLESTON, *Chairman*,
School of Mines, E. 49th Street, N. Y.
E. D. LEAVITT, JR., *Cambridgeport, Mass.*
W. METCALF,
Miller, Metcalf & Parkin, Pittsburg, Pa.
OBERLIN SMITH, *Bridgeton, New Jersey.*
C. J. H. WOODBURY,
13 *Devonshire Street, Boston, Mass.*

Prof. Hutton.—I move that the committee be thanked for its services, that the committee be continued, and that the report be accepted and printed.

Agreed to.

Mr. Woodbury.—I move that the Secretary of the Society be instructed to transmit to the Pratt & Whitney Company of Hartford, Connecticut, an attested copy of the report of the Committee on Standard Measurements.

Agreed to.

Mr. Oberlin Smith.—I beg to offer this resolution:

Resolved, That the hearty acknowledgments of this Society are due to the Pennsylvania Railroad Company, the Hudson River Tunnel Company, the Brooklyn Bridge Company, the New York Steam Company, the Morgan Iron Works and the Brush, Edison, and United States Electric Lighting Companies, for courtesies rendered and attentions shown to its guests and to itself, and that the Secretary be ordered to convey to them the sense of this resolution.

Agreed to.

Mr. Woodbury.—I beg to offer this resolution:

Resolved, That the thanks of the Society are due to the local Committee of Arrangements for the annual meeting, and especially to its Sub-Committees on Excursions and on Printing and Press Notices, for their most effective and satisfactory action in the duties with which they have been respectively charged, and that the Secretary is hereby instructed to communicate to them this resolution.

Agreed to.

The President.—A part of our work of yesterday has been omitted. We had a paper by Mr. Smith on "The Preservation of Drawings," and we were compelled to omit the discussion of the paper owing to the lapse of our time this morning. Has any gentleman any remarks to make upon the paper on "The Preservation of Drawings," which was heard yesterday? Is there any discussion? If not, we will go on to the next paper by Prof. Webb on a "New Form of Indicator."

Prof. Webb then read his paper, and discussion followed.

At the close of the discussion, the President gave the invitation to visit the stations of the electric lighting systems.

The President.—I will say here, before calling for another paper, that the gentlemen are expected to meet the Presidents of the Electric Lighting Companies immediately on adjournment. They will explain their methods at the Hoffman House, and then there will be an opportunity of visiting their stations and seeing the machines in operation. Is there any other business to be presented?

Mr. Holloway.—I do not know that it is necessary to make a motion; but I desire to say, before the meeting closes, that some of us would desire to have the committee on future meetings, or the Council, take into consideration the advisability of having the next meeting in some Western city—possibly Cleveland.

The President.—The Council have taken no action as yet in the matter, and there has been no invitation extended to the Society to meet at any other point. There is a strong disposition among

members of the Society and of the Council with whom I have talked to make the next meeting a Western meeting; the feeling being that we are localizing our Society too much by having so many meetings at the East, and it is probable that a favorable inclination will be formed to meet in Cleveland in the Spring.

Mr. Holloway.—I would say on behalf of the Western members that such a plan would be satisfactory to them.

A paper by Mr. Alfred Colin on "Technical Schools for Artisans" was read by the Secretary, and elicited no discussion.

After a paper by Mr. Norman Wheeler, entitled "Launching Ships Side-On," was read by title, the meeting adjourned, subject to the call of the President and Council.

After adjournment the members repaired to the Hoffman House to inspect the effect of electric light on paintings, and were thence escorted to the station of the U. S. Electric Lighting Co., using the Weston Dynamos, and to the station of the Brush Illuminating Co. It had been planned to visit also the Edison station, but on account of the lateness of the hour the plan was not carried out.

ALEXANDER LYMAN HOLLEY—A MEMORIAL ADDRESS

BY

R. W. RAYMOND, PH. D., NEW YORK CITY.

MR. PRESIDENT, GENTLEMEN OF THE AMERICAN SOCIETY OF CIVIL ENGINEERS, THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS, AND THE AMERICAN INSTITUTE OF MINING ENGINEERS; LADIES AND GENTLEMEN:

The memorial session in Washington, at which I was first designated for the duty of this evening, was chiefly devoted to the multiform expression of sorrow. From a score of speakers, who had known Mr. Holley in various stages of his career, came tributes of affection, honorable alike to him and to them. Among them all, none uttered words more heartfelt and impressive than did the venerable Ashbel Welch, who, by reason of official position, as well as years and character, would doubtless have been called to preside over this meeting, had not a more potent message summoned him meanwhile to a higher seat. Nestor mourned over Achilles, slain in the midst of the battle; and now Nestor, too, from the peaceful life of an honored old age, has passed away.

But neither this more recent, nor that earlier, grief is the theme of the present hour. However inadequate to the task the orator of to-night may prove, it was fitting that some one, waiting until the first outburst of emotion had died away, should attempt a calm review of the life and works of Alexander Lyman Holley; that Friendship, bewailing her loss, should give way to History, counting her gain; that the achievements of the departed should be recognized and valued, and his example studied. Was he greatly successful? How did he win success? How much of it was born with him; how much thrust upon him; how much earned by him? And if his own hands wrought out his fame, is there any thing in the method of his preparation and practice that others might imitate with profit?

Mr. Holley was born at Lakeville, in Salisbury, Conn., on the 20th of July, 1832. His father, Alexander H. Holley, subsequently Governor of that State, was a native of the same village. His

mother, whose maiden name was Jane M. Lyman, was one of the Lymans of Goshen. The experts in New England genealogies will not need to be told that, on both sides, he came of a good stock—such as, by a combination of enterprise, intelligence, and high principle, has made New England great. The mother could, indeed, bestow upon her son nothing more than the legacy of inherited character, for she died a few weeks after his birth. But her place was supplied by the second marriage of his father, three years later, to Miss Marcia Coffing, whose affection, bestowed freely upon her stepson through twenty years, was as freely returned by him. Their correspondence, some of which has been preserved, shows that their personal intercourse was intimate, and that this excellent lady, though burdened with the cares of a large and hospitable household, never forgot to be a true mother to this son of her adoption, as well as to the children born of her. No doubt he was much indebted for noble impulses and principles to the influence of this devoted woman.

For two or three years of his early boyhood he attended the district school near his father's house, and was then advanced to the Academy, to which he walked, a little more than a mile and a half, every day, winter and summer. In later life, he was accustomed to allude to this regular exercise as having laid the foundation of the fine constitution which enabled him, for so many years, to work so hard and yet so easily.

From the Academy in Salisbury he went to another, under the care of Mr. Simeon Hart, at Farmington, Conn., and after a year or more, to Williams Academy, them directed by Mr. E. W. B. Canning, at Stockbridge, Mass. From Stockbridge he went to Bridgeport, Conn., to prepare for Yale College, under Rev. Henry Jones. According to the dates and internal evidence of his boyish letters, the above order is not strictly correct. I find him at Stockbridge in 1846 and 1847, at Farmington in 1848, at Bridgeport in 1849, and back at Stockbridge in 1850. For our present purpose, the question is not important, except as it shows an early trait in his character—a restlessness, born of versatility and genius, which under less judicious training might have wasted his life.

Ample and interesting materials tempt me to more detailed description of his boyhood. But I must be content to mention, and briefly illustrate, its leading characteristics. First among these must be named the normal, healthy physical activity and the overflow of mirth and high spirits which made him a leader in boyish

sports and adventures. Where the others climbed with ostentatious courage up to the belfry of the academy, he, at the first trial, mounted above it and stood on the gilded ball, which no foot had pressed before. He hangs over precipices, takes long foot-journeys, and revels in mere consciousness of life and strength. Strikingly handsome as well as athletic, he is naturally a leader among his comrades. In all sorts of home amusements, too, his merry ingenuity makes him invaluable. Many of these, such as charades and rhyming games, were intellectual; others were mere pranks—such as the match between him and a friend, "who could eat the most pancakes," of which the kitchen was the scene, the cook being coaxed into complicity, and the dog, wagging his tail behind the combatants, received from each as many segments as could be surreptitiously bestowed without the knowledge of the other; or the occasion, when, having constructed a rustic bridge over the brook, Holley forced the entire family to march over it in solemn procession, while he sat by, fantastically dressed as a troubadour, and played the guitar.

Let no one despise this light-hearted gayety. It was the early form of that courage which carried him afterward through many struggles and even defeats, with an air of victory that was in itself the promise of victory to come.

To this quality must be added a keen observation and an inborn talent for drawing. These were specially, but not wholly, directed toward machinery, in which he took the liveliest interest. His father having established the well-known knife manufactory at Lakeville, the boy made himself familiar with all the machinery, and during his youth made innumerable proposals of improvement—some of which, being really good, were adopted, while others—no doubt the greater number—were crude and impracticable. When but nine years old, he accompanied his father as far as Niagara, where he was left for a few days with an uncle who was connected with works employing machinery. During the father's absence, Alexander was repeatedly missed by his uncle, who always found him on such occasions in some place where there was a steam-engine, and who long preserved, as a memento of the visit, a little bundle of papers on which the boy of nine had made drawings of the different machines he had thus studied. In a letter written at about the age of fourteen, he describes an excursion with his schoolmates to the old Bristol copper mine, six miles from Farmington, and says:

"The steam-engine attracted considerable of my attention, of course. It was splendidly made and fitted, and went so still that one would hardly know that it was in the room. Power, twenty-horse. Mr. S. Hart [his teacher] told the gentleman that showed us around that he would have me draw a plan of the engine from memory, which I have done, and which Mr. H. is much pleased with. He says he is going to send it to the aforesaid gentleman at Bristol."

His letters overflow with revelations of his passionate interest in machinery, and particularly in locomotives. In one of them, written after returning to school from vacation, he indulges in some of the truly good sentiments with which boys are wont to please parents, but which are in this case redeemed from platitude by this picturesque touch:

"It seems as if I should dive and dig and plow, and if that did not succeed, back out and plow again, in my studies, as faithfully as the locomotive old 'Connecticut' did, this morning in the drifts, with seven long cars, all alone."

In another letter, he speaks of a locomotive which has been wrecked on the Housatonic road; calls it by name, as an acquaintance; says he has walked twice (a number of miles) to the place where it lies at the bottom of a steep embankment; introduces a pen-and-ink sketch of the scene, locomotive and all, to show how difficult will be the return of the engine to the track; and concludes, "I guess the H. R. R. Co. will not make money by this operation."

He frequently declares his determination to master the science of machinery, and I find one sentence, in a letter written at fifteen, which seems to be an unconscious prophecy. He writes:

"I have seen, in a newspaper, an account of a man in England who makes steel that will cut iron or any other hard substance without dulling it. I should like to hire out to that man for a year or so. * * * I wish I could learn the art of making steel."

Twelve years later, there was a man in England by the name of Bessemer, of whom he took, in this art, lessons that were not wasted!

In another letter, written from Stockbridge, he says:

"I have been devoting all my leisure time, for nearly two weeks, to making sectional and perspective views of the internal works, machinery, steam-works, etc., of the most improved locomotive engines, showing how the steam is made, applied, and cut off at half-stroke or not (a recent improvement); how the engine is worked every way, in some seventeen different pictures, with explanations filling some eight or ten pages. Mr. Canning is to have them framed and hung up in the Academy. I have explained them in such a manner that any one can understand them, and I really hope that people will look at them, for there is more ignorance among scientific and educated men on this point than

on any other. People who pretend to 'know the ropes' cannot explain the simplest form of a steam-engine, even with a model. Of mechanics and chem istry, I intend to get the most thorough knowledge, if I have the opportunity (and, in fact, I intend to get it any way), both practically and theoretically. These are the studies I have always liked, and I am bound to investigate and become master of them."

One other characteristic deserves special mention—his talent for debate and literary composition, and his consequent love of them. Let it be said here that his was not an instance of dropsical precocity. His early efforts were not mature, or even suprisingly early. At fourteen he joined, I believe, his first debating society. I have found, in his handwriting, a constitution and by-laws of the Societas Literarum (symbolized by a Greek Sigma), which bear date about this time, and in their simplicity and brevity are worthy of imitation. The constitution runs thus:

"1. It shall be the duty of each member to try to sustain the society.

"2. Each member shall pledge his word of honor to keep all the proceedings a secret.

"3. The business of the society shall be debating and composition reading.

"4. This society shall support a semi-monthly paper, called the ——." [Name omitted.]

And the following are the by-laws:

"1. The officers of the society shall be a secretary and a president.

"2. There shall be as many as eight members in the society.

"3. It shall be unlawful to use vulgar or profane language."

It was not long, however, before, in this congenial sphere, he developed extraordinary activity. I cannot forbear to introduce, at this point, the letter which appeared in the *American Machinist* of March 18th, 1882, from Mr. Canning:

"The universal sorrow in the inventive and mechanical world over the recent decease of A. L. Holley prompts me to jot down a few particulars of his earlier school experiences, which go to prove the truth of the proverb, 'The boy is father of the man.'

"Mr. Holley entered Williams Academy at Stockbridge, Mass., in the fall of 1848,* then under my charge. He is still remembered as a fair, fresh-cheeked, blue-eyed, wide-awake boy of sixteen, who pursued studies preparatory to a college course. His geniality, generosity and overflowing good humor made him popular with his schoolmates, and soon gave him the lead, both in and out of school. He excelled in every branch of study; but his chief interest centered in Natural Philosophy and Mechanics. He was a prominent member of a literary society of the institution called the 'Philologian,' in which he mani-

* Mr. Canning forgets his first sojourn at the school. He was certainly there in 1846 also.

fested talent unusual for his years for debate and free discussion; while his fun-loving propensities found vent in conducting mock trials and in humorous essays and declamations. He established and mainly conducted a periodical entitled *The Gun Cotton*, issued fortnightly on a large sheet in manuscript, which was read by himself from the desk, and afforded great interest and amusement by the variety and spice of its contents. This he edited during his stay at the Academy.

"Though excelling in all the branches of study required of him, his *penchant* for mechanics and invention developed itself markedly when he attacked Natural Philosophy and Physics. Dissatisfied with the meager description in the text-books of the steam-engine, with which he seemed to be better acquainted than the authors of the treatise, he at my request made drawings in detail of a stationary engine and of a locomotive, with an accuracy and skill that would have done credit to a professional engineer or draughtsman. These I used in demonstration, in preference to the imperfect model among the school apparatus. During one of his vacations, he came up from his Salisbury home expressly to show me a miniature engine of his own building. It was complete in all respects, and of skillful workmanship; and, on being fired up, ran with admirable success. Thus he foreshadowed the devotion to the mechanic arts which so eminently characterized his manhood. One number of his *Gun Cotton*, I remember, was devoted to the description of an aërial voyage made by a machine of his own devising, whose practical workings were related with as much interest as the details of the wonders of sight-seeing it enabled its inventor to describe. This, he prophesied, would be substantially the vehicle of locomotion A.D. 1950.

"His temperament prompted him to constant activity. There was not a lazy bone or muscle in his body. In fact, his mind was too powerful for his physique; and, beyond doubt, the continued high-pressure at which he drove his mental energy, during all his busy life, materially shortened his days.

"In his reading he was fond—though by no means exclusively so—of works of imagination. Every new invention that fell under his eye received due notice in his *Gun Cotton*. Imaginative works seemed to be the whetstone on which he sharpened his own inventive genius. It is rare that good sense and sound judgment succeed in subduing the *imagination* to become the servant of the *practical*, to the extent realized in the case of Mr. Holley.

"Your brief but comprehensive article in the *American Machinist* of 18th of February follows the career of Mr. Holley subsequently to his college life. Doffing the student's toga for the workman's blouse, he put to the test the best theories of his book-learning, and showed the world, to its immense benefit, the unusual example of a man possessing the combination of enlarged education, inventive talent, and practical common sense.

"*Stockbridge, Mass.* E. W. B. CANNING."

To this life-like picture no improving touch could be added, unless by the hand of the subject himself. One or two quotations from Holley's letters of this period will be their own sufficient apology.

Writing from Bridgeport, at seventeen, and giving, as was his custom, an account of his doings, he says:

"I have written the following compositions:

"1st. A Dream, personifying Wisdom (a judge), History, Chemistry, Mathe-

matics and Philosophy, who speak of their respective merits. Philosophy wins the prize. 6 pages of foolscap.

"2d. A Fragment (revised from a former) containing a few thoughts like those in Gray's Elegy. 2 pages.

"3d. History of Audax Promptusque. A novel. 26 pages.

"4th. War (revised from a former). 4½ pages.

"5th. Pride (rather disconnected). 2 pages.

"6th. A Picture. 6¼ pages. On this I have spent in all at least twelve hours' hard study, and it is the best composition I ever wrote. I would like to have you read it.

"7th. A Dream and Consequent Wish. The best I ever wrote, except No. 6.

"8th. A composition in blank verse. Unfinished."

In January, 1850, he writes from Stockbridge:

"I write you in great haste, to say, that at the close of the term we're to have an exhibition. I was first chosen to write and speak a valedictory oration. Then I have to write the *Gun Cotton*, and a continuation of a treatise on the manufacture of pocket cutlery (which I have been at several weeks), for the *Experimenter*, another paper—all this for the day of exhibition. Then the forenoon of the day is to be occupied by a lawsuit. The Philologian Society have, for that occasion, resolved themselves into a 'high court of inquiry,' and I am chosen for 'State's Attorney,' to prosecute a man for 'assault and battery.' This will be public. Besides this, I have to write a continuation of my treatise on 'Cutlery' for the *Experimenter* next week, and to write two numbers of another paper I publish, called the *Locomotive*. Then I have to prepare also for a public trial next week in the Philologian, also to learn (probably) a part in a dialogue for exhibition, and all this in addition to Latin and Greek. My request is this, that I may omit my music lessons till next term, as I have my hands full, and shall burn some of my irons, if I don't look out.

"I shall also want a new coat to expatiate in on the great day. Please send as soon as convenient."

The treatise on "Cutlery," above alluded to, was subsequently accepted by Poor's *Railway Journal*, and published in successive numbers of that paper during the summer of 1850. It is a curious compound of learned extracts from such books of general chemistry, etc., as were accessible to the young author, and admirably clear and vivid descriptions of the actual processes of the manufacture with which he was personally familiar. In his ambitious view, the subject of pen and pocket cutlery includes the natural history and chemical and physical relations of iron, steel, brass, copper, zinc, German silver, tortoise shell, etc. No element is mentioned without a conscientious statement of its chemical equivalent, and the manner in which it is produced or found in nature. But these adornments of the essay, probably its principal merits in the author's opinion, are worthless in comparison with the practical details, which no doubt chiefly commended it to the publishers.

This was, I think, the first literary work for which he received pay. In an exultant but apologetic letter written in July, 1850 (after the publication of the treatise had begun), he confesses that he had made a surreptitious journey from Stockbridge to New York:

"I walked before sunrise to West Stockbridge, went to Hudson and down the river on the *Alida*. Called on Mr. Poor, who was sorry he had paid no attention to my dozen letters, and as a compensation gave me the equivalent of about sixty dollars for my essay. That is, he gave me $25 in cash and 27 copies of every chapter of the article, thus making probably 243 *Railroad Journals*. * * * He says I had better enlarge the essay a little, and come down in vacation to New York, when he will introduce me to a house in New York, who are perhaps the largest publishing house in New York. He thinks I can sell the copyright. I saw the steamship *City of Glasgow* sail. City in mourning for General Taylor. Left the city at three o'clock. We had two locomotives and eleven cars full out."

One further trait, and our picture will be as complete as circumstances will permit us to make it. I have already alluded to the restlessness of Holley's mind. He is drawn by many tastes and ambitions in many directions, though through it all his dominating tendency may be perceived. He is impatient of processes and longs for results. Sometimes his distaste for the drudgery of books and the discipline of school rises to despair. Thus he writes from Bridgeport, in 1849, to his father a letter from which I take the following extracts:

"I have had every thing done for me that could be done—every thing that kind parents could possibly do for a son. I have made three trials, and each one has proved unsuccessful—three trials to get an education; and now having spent so much of your money and trouble, I wish to make one trial at work; and I know I can succeed. * * * It is a waste, sir, I think, to send me to school. It is not in my nature to deprive myself of an education if I was able to get it; but I see the folly of it. I have tried as hard as I could to learn out of books, but it is folly in the extreme. *If* I have any talent at all, it is for writing. When I lay myself out and spend many hours on a composition, I can, by copying all the good parts, make out quite a piece; but this is *all* the talent I have got, *any way*. Now I have got hands and can work. * * * There is John [his brother], a natural scholar, who could not bear hard work, and who will make, by his mind alone, a great man; but I can work, and do nothing else to any advantage. * * * I am very anxious, of course, to hear your decision, and will come, if you say so, with a right good-will; but if not, it all looks *dark* ahead, and I do not know what I shall do. * * * P. S.—Please write to-morrow, as I am very anxious to hear."

The key to this exaggerated confession of failure doubtless lay in the fact that at this time he was preparing for the classical course at Yale, and was giving a good deal of trouble to the Rev. Mr.

Jones. Moreover, going home to work meant escaping from the bondage of Latin and Greek to the whirring wheels, the engine, the forges, the tools of that *knife-factory!* On one hand, purgatory; on the other, paradise; what marvel that to his vision the disciplinary pains of the former took on the hopeless hues of utter despair?

I violate, in this one instance, the rule I have elsewhere pursued in the treatment of private correspondence intrusted to me, by quoting from the reply to the foregoing letter:

"I am very sorry to see you yielding to so desponding a tone of spirit. You are not quite the dunce you would attempt to make me believe you are, nor have all your experiments to secure an education failed, as you would intimate. You certainly know more than you did, when you commenced your career abroad, about books and about men and things. I have certainly had two or three reports to that effect. Why then do you despond? I have not complained of your scholarship in writing to you. * * * This complaint has been on your part and not on mine. * * * No, my son, you must not despond. If dark days now appear, brighter ones will follow. * * * Have you not often heard me say how grateful I always felt to my father, that he did not indulge me in my propensity for change? I think I should have been a ruined man if I had been permitted to hop from this thing to that, and hither and yon, just as fancy for the time might dictate. I wished to leave the store and engage in farming. He said no, and I felt hard about it; but I have often since thanked him for that *no*. Besides, suppose you were to leave school and engage in business systematically (which you never have done yet), and were subject to the drill which you must be, when that time does come, would not that after awhile be as irksome as anything else? * * * You are in the right way now, my son, and your future happiness, usefulness, and respectability depend upon a continuance in this. Of this, I assure you, as a father most earnestly desiring your happiness as well as usefulness.

"If you are not ready to enter college at the next commencement, then go on till you are ready. There are more years to follow. Only make good use of your time, and we shall all be satisfied. * * * You say you think you have *one* talent at any rate. I think you have more; but cultivate *that* at all events, and do all you can towards cultivating others. The cultivation of this very talent may yet be essential to your success in life.

"But always remember one thing, my son. It is an injunction of the Most High. Man is to earn his bread by the sweat of his brow. From this there is no escape. Therefore we must keep on in our employments, whatever they may be; and the more cheerfully we do so, the happier we shall be. Brighter days are before you, and you will so see it ere long. Be contented, then, and make us happy and yourself happy, and all your friends happy, by a cheerful perseverance in the duties before you, which are not *always* study, but in after years the *fruit* of study, and all will be well."

An excellent letter; and there were many more of the same sort. But wiser than wise words was the step that followed; for the father, while holding a firm hand upon these wayward moods, was not blind to the needs and impulses of the genius beneath them; and

in 1850, Brown University having just established a scientific course, Alexander was entered at Providence instead of New Haven. From this time on, nothing was heard of discontent in his study. In October, 1850, he writes:

"I have succeeded, by working nights and in odd hours, in making a painting of the fastest locomotive in the city, which I showed to the Professor of Mathematics. He was pleased with it, and asked me to go with him and look at the locomotive, and to explain to him a new invention in locomotive engineering, called 'link-motion,' which I did satisfactorily. I considered this quite an honor, as he had explained the steam-engine to classes for a dozen years or more. He then took me into several factories where I could not have gone without him."

Besides the picture above referred to, he finished a working-model of a steam-engine, which the professors assured him was the best they had ever seen. And what was more important, he invented a new cut-off, concerning which the following extracts are interesting:

"Brown University, November, 1851.—* * * I have noticed Professor Page's engine, of which father speaks. As he says, it will eventually do away with steam, but *not yet*. I understand his magnetic engine perfectly. It is just as capable of improvement as the steam-engine—and more so. Machinists' work is also quite as necessary for it as for steam-engines. At any rate, I have invented an improvement in steam-engines, and it is bound to be patented, if I sell the coat on my back to pay for it, and go without any. I have showed my plans to a man who was four years with Messrs. Corliss & Nightingale, of this place. These men have invented and are making the most improved cut-off engine of the day, and this gentleman says that my engine (that is to be) embraces all their improvements and none of its disadvantages."

"January 14th, 1852.—After many attempts to get time, I have at last succeeded in putting my new cut-off on paper. Professor Caswell says that it will work as well as Corliss's celebrated cut-off. Professor Norton says it is very ingeniously contrived, and is better than Corliss'. To-day I took it to Mr. Greene (of the firm of Thurston & Greene, the most extensive engineers in the city), and he said it would work as well as any cut-off he ever saw. He said I could not get it patented, for this reason. A man, some years ago, got up a cut-off, and in his patent it was provided that he should own all improvements in the cutting-off of steam by the regulator, wherein the valve-motion was obtained by any *connection* with the working part of the engine. My cut-off is *entirely* different in principle and form from his and from all others; yet Corliss himself, whose cut-off is different from his and mine, is to-day involved in a law-suit with the original inventor. * * * I feel satisfied, at all events, that my plan is entirely original, and as good as anybody's. * * * I can have a picture and description of 'Holley's Improved Cut-off' circulated in *Appleton's Engineers' Journal* [he means the *Mechanical Magazine*], free of expense, and shall immediately do so. [This cut-off was illustrated and described in the *Mechanical Magazine* in July, 1852. It is a detached escapement, operated both directly by a cam (at the end of the stroke), and indirectly from the governor, at any point during the stroke.] * * * You advised me when I was home to consult Mr. Adams, C. E., of New York,

about my oscillating engine. I did consult him, and found that my fundamental improvement, on which the rest depended, was patented in England by a celebrated engineer, some years ago. I thought it all out myself, and never heard of it till I had put it on paper myself."

Although such matters as these occupied much of his attention, he was active in the literary society to which he belonged. A letter to his step-mother pours out his wrath at the injustice to which the college societies were subjected by the President and trustees, when, desiring permission to meet in the evening instead of the afternoon, they were flatly denied. A rebellion followed, but though some of the hot-heads went so far as to incur the peril of expulsion, Holley stopped short. After all, what he wanted was to get an education, and to him these minor issues were not important enough to justify the risk of losing that. So he declined to abet further the revolutionary movement with which he heartily sympathized, and turned his tumultuous feelings into the safer channel of a long, eloquent, and indignant letter home.

It was either before or just after his graduation that he wrote an elaborate essay on "Water Considered as a Carrier," which was published in 1854 in successive numbers of the *Litchfield Inquirer*. It is an exhaustive account of the functions and properties of water as a conveyer of gases, mechanical sediments, dissolved salts, germs, etc., in the vegetable, animal, and mineral kingdoms; of its agency in geological formations, volcanic eruptions, etc. Curiously enough water is considered as a carrier of every thing except heat. This aspect is omitted altogether, though it is the one with which the writer was at that time most familiar, and was afterward to be most largely concerned. The essay came from his reading, not from his experience. It is creditable to a young collegian; but still more creditable is the fact that he never wrote another like it.

In September, 1853, he was graduated, with the degree of Bachelor of Philosophy. His oration, on "The Natural Motors," is in point of style not notably different from the fervid and florid efforts common to such occasions. Yet it betrays throughout the passion of the speaker for locomotive machinery, terrestrial and marine; and two passages, describing respectively a locomotive and a steamship, show with what assiduous affection he has watched what he describes. Less clear and forcible is his allusion to electricity, the employment of which in the telegraph he represents with "commencement" rhetoric, as "ambitious man, grasping the red right hand of Jupiter!" But he pays a compliment to the

caloric engine, as an enterprise which "may yet be consummated in a future neither chimerical nor distant." This was just after the trial of Ericsson's steamer, and before the general recognition of the fact that heated air is useful and economical for small motors, though it cannot compete on a large scale with steam. I use the words of the distinguished inventor of the caloric engine—a man whose brilliant list of great successes renders him well able to afford the confession of a failure, and who, in the true spirit of science, has drawn from this disappointment grounds for gratitude. "The marine engineer," writes Mr. Ericsson, "has thus been encouraged to renew his efforts to perfect the steam-engine, without fear of rivalry from a motor depending on the dilatation of atmospheric air by heat." (*Contributions to the Centennial Exhibition*, 1876, p. 438.)

Holley's faith in the genius of Ericsson was confirmed in later years, in connection with the triumphs of the screw propeller and of the turreted iron-clad. And Ericsson's generous appreciation of Holley appears in a letter written since the death of the latter, and speaking of him as "the brightest ornament of American engineering."

After leaving college, Holley entered the shops of Corliss & Nightingale, at Providence. They were at the time engaged in the attempt to apply to the locomotive engine the principles of the variable cut-off, so successful in the stationary engine. Holley entered the locomotive department, where he served both as draughtsman and machinist, and subsequently took the "Advance" out on the Stonington Railroad, where he ran it as engineer long enough to show the practicability of so doing, and, I believe, to effect the sale of the engine. In economy of steam, as shown by indicator diagrams, the "Advance" was superior to existing link-motion and lap-valve locomotives, but the detach variable cut-off was too delicate an arrangement to endure the jar of such rough service. Another arrangement was substituted; but this, too, rattled to pieces; and even in the form finally adopted, the "Advance" was not practically a machine to be enthusiastically welcomed, particularly upon such road-beds as were then characteristic of America.

In his speech on "The Pursuit of Science," at the Hartford dinner of the Society of Mechanical Engineers, Holley revived his reminiscences of the "Advance." Said he:

"The idea began to obtain that science should be pursued not in books, but in things; and I commenced the pursuit of science in and on and under one of

the awfulest *things* this world ever saw. It was Corliss's original locomotive, euphoniously called, 'The Old Jigger.' This locomotive was possessed of a certain inborn cussedness, which could hardly be the attribute of a mere machine—her spiritual nature was a sort of Mephistophelian cross with a Colorado mule—and as to her physical constitution and membership, a cotton-factory 'mule' was simple in comparison. The Old Jigger had, as nearly as I can remember, 365 valves, one to break down every day in the year. And as a valve *motion*, well, nobody ever counted the number of its pieces. They were as the sands of the sea-shore. Most of them used to jar off, the first few trips of the week, after which all the men in the shop could comparatively keep track of the rest of them. I will say for the Old Jigger that she made the best indicator-card I ever saw from a locomotive; clean cut-off, almost a theoretical expansion curve, and an exhaust as if she had knocked out a cylinder head. Well, once in a while, after she had been jackassing over the road about four hours behind time, and we had pinch-barred her into the round-house, we used to pull out these indicator-cards of hers, and talk them over right before her, and we would look at her and ask one another why in thunder an engine that could make a card like that would act as if the very old—chief-engineer was in her. And next morning she would rouse up and pull the biggest train that had ever been over the road—ahead of time.

"But she was an inconstant old girl—and lazy, too—used to prefer to work with one side, and always made some plausible excuse for breaking down the other. I remember, one March morning, when nobody was looking, she kicked off about two dozen pieces of her starboard valve-gear, and brought up all standing, over a culvert about ten feet wide and full of ice-water. As I was standing in this culvert up to my middle, disconnecting her eccentric straps, a college professor came along, and rammed his umbrella into me, and asked me to explain to him the difference between this locomotive and any other locomotive! I then delivered my first scientific lecture; and I am now of opinion that its diction would have been modified by a divinity student!

"Continuing my pursuit of science, I left Corliss's works with a knowledge of valve-motion which was simply sublime; and I then proceeded to engraft this knowledge on a locomotive works in the Middle States."

So far, the dinner speech, delivered in May, 1881. How lightly does memory pass over the sad hours of the past! Probably the witty orator would have been as much startled as his hearers if any voice had recalled to him the period of despondency, through which he had passed after leaving the Corliss shop, and before finding employment elsewhere. Messrs. Corliss & Nightingale wrote, under date of March 27th, 1855:

"Mr. Holley has been employed for nearly eighteen months in the locomotive department of our business. He is an accomplished draughtsman and exhibits talent in the designing and application of machinery. During the time he has been with us, he has enjoyed every facility for becoming practically acquainted with the working of locomotives. We should be glad to avail ourselves of his services in our regular business of manufacturing stationary engines. But his mind is on locomotives; and therefore, into that branch of mechanism will he carry that spirit and aim that will insure success. As we do not propose to

pursue the locomotive business at present, Mr. Holley leaves us, and carries with him our best wishes for his success."

Armed with this and other introductions, he visited the principal locomotive shops of the West in search of employment, with the result stated in the following letter, written about a month later, in St. Louis:

"I am completely discouraged. I have applied at every place in the Western country where they build locomotives, except one (at Milwaukee), and I am informed that I shall find no opportunity at that place. At Detroit, my letters were of no avail. They wanted no draughtsman, only made the locomotive business a minor affair, and did not propose to try to establish a reputation of their own—as nearly as I could understand it. Mr. ——, of Cleveland, had no place for me, and said that if there was anything in the world he hated, it was patented improvements. Niles & Co., of Cincinnati, had a first-rate draughtsman, and would not change. * * * —— & Co., of Cincinnati, only build a few machines and hired a draughtsman, as they used a turning-lathe, for mechanical labor only. They get some poor fellow who will work a month or two, and then starve a month or two when they don't want to use him. The Covington, Louisville, and Chicago works have suspended. The shop at St. Louis is a good one; but they could give me no encouragement, though they seemed to be anxious to drive business. They have no draughtsman at all, and think that people here are too ignorant to desire any change in the old form, even though it might be an improvement. I even offered to work for almost nothing, at almost anything, if they would take me in, but was unsuccessful. * * * It is strange that when I have taken such pains to represent myself modestly, and am willing to do anything and work and persevere to the utmost extent, that when I have got such strong letters, and that when I know that I can build a better locomotive than all the rest of them put together—even in the face of all this, I cannot in the whole Western country get a place to earn my daily bread. The idea is damning to a man's spirits; though sometimes it looks so ridiculous that I cannot but laugh at the world generally. One thing is certain—I *will* build locomotives; and if my life is spared, I will ultimately place myself in a position where I can look down on every man who has neglected me, and laugh with a good will at the bad luck which the *improvements* they scorn have brought upon them. It may be a long time before I shall get my head out of water, and I sometimes fear that my spirit will fail me before I see the daylight. If I sink, poor and unknown, I honestly believe I shall drag down with me some ideas of which, however humble they may be, the world is not worthy. * * * I want to visit the Philadelphia, Baltimore, and New Jersey works, and see if I can convince myself and my friends that I am good for something. If I fail in doing this, I am ready to sink; for if there is anything certain in this world, it is that I will NEVER *do anything* permanently for a living but just this one thing, namely, building locomotives."

It was at the very end of his hopes—in the locomotive works at Jersey City—that he found employment at last. And it was while he was working there that he, most improvidently and most fortunately, married. It is not my purpose in these remarks, devoted

as they must be to his professional career and works, to intrude upon the sacredness of his domestic life. Yet the two are not altogether separable. There are those who have not forgotten how the young wife trudged daily with her husband to his experiments with coal-burning locomotives on the Harlem road, or assisted him in the office of the *Railroad Advocate*, or haunted the new Bessemer works at Troy, until he was accustomed to say, when fears were expressed for his health, "Don't be afraid; if I die, *she* can run the concern." More than this: from the date of his marriage we find in his letters no more outbursts of despair, but the cheerful and sanguine courage of a heart anchored in a happy home. Into that home, trouble and death came, as whither do they not come? But they could not banish peace and hope. Many of you will remember Holley's humorous and pathetic address at the Pittsburg banquet of the Institute of Mining Engineers in 1879. Replying to the toast of "The Fellows' Wives," he said, among other things:

"Young man of the school, full of lore and anxious for hire, what is the vista of probabilities that fills your eye? Will you map out the metalliferous veins under the fair landscape, from the ragged outcrops of the upturned rocks? Will you span the cañon, eroded throughout æons, with your gossamer steel bridge of yesterday? Will you compel a river which denudes a continent to build out its own ship-canal through its own delta with its own *débris?* Will you sever continents to make a highway for commerce? Will you coax out of ores with your deft alchemy the metals which the evolution of ages put in? Will you drive a train from the Orient to the Occident, following the sun, and keeping company with the hours? Ah, my dear boy! these things you may do; but they are only means to an end. And that end you shall see down the long vista of the inevitable. There, with eloquent eyes and folded arms, sits a dear little woman. And, my boy, when those tender arms shall enfold *you*, and those eloquent eyes shall flash into your soul the potential caloric of a whole life, then you will know what it is to be the lord of a fellow's wife. * * * Two thousand years ago, the philosopher Callimachus, wandering in the cemetery of Corinth, was arrested by a vision of prophetic beauty. It was only an acanthus plant confined in a basket and covered with a tile, the struggling leaves curling through the meshes and wreathing themselves in graceful volutes under the covering stone. This was the decoration of a child's grave; but it was the prototype of the Corinthian capital. As out of a little grave grew the glory of decorative art, so out of, ah! how many little graves, struggling through the meshes and repressed by the cold marble, perennially bloom the graces and the virtues of the higher life—that long-suffering, that patience, that elasticity, that sweetness, that association of the good and the beautiful, which is but another name for *the fellows' wives!*"

While yet at Corliss' works, Mr. Holley had written both for the *Polytechnic Journal* and in Colburn's *Railroad Advocate* articles on the Corliss engines, which displayed marked ability. Probably it was this which brought him to the notice of Zerah

Colburn, the inconstant, erratic, unfortunate, but brilliant and wonderful engineer and author, whose fitful career would in itself be subject enough for a volume. Mr. Colburn had been superintendent of the New Jersey Locomotive Works, and had started in 1854 the *Railroad Advocate*, which may be said to have inaugurated a new era in the technical journalism of this country. From being a contributor to this paper, Holley became a partner and editor. The two men had many things in common. They were in love with the locomotive, and all that pertained to it. Their scientific knowledge had a foundation of practical familiarity with the topics of which they wrote. Colburn was the superior in the range and maturity of his professional knowledge, and it is impossible not to recognize the great advantage, intellectually, which his younger associate derived from this companionship. But in other respects, Colburn was no comfortable yokefellow. He could not bear harness. After a year, he sold out to Holley, and from April 19th, 1856, the *Advocate* was published by Holley & Co. In August of the same year, the name was changed to *Holley's Railroad Advocate*, though Colburn still wrote for it occasionally, and for about a year the burden, both of editorial and business management, was borne by Holley. His letters show that it was not light. In January, 1857, he writes that the paper is "filling up with advertisements at $24 an inch;" in February, he is still sanguine, but says that "like all other things, it is slow at first." He adds, "I must be traveling most of the time, and picking up all that is new, to keep up the interest in the paper, and must keep it full of advertisements. I cannot edit the paper in New York, or in any less space than several millions of miles." In March, he writes from Lynchburg, Va., that he has progressed slowly, but thinks the trip will be pretty successful. He will have some $300 worth of advertising from Richmond. The country is not so dilapidated as he expected to find it. Things are lax and dirty, but there is a good deal of enterprise in the larger towns. He expects to go on as far as New Orleans and Cuba.

The *Railroad Advocate*, caught in the storm of the great commercial crisis, was sadly battered, if not wrecked. It never fulfilled his hopes, as a business; but we cannot fail to see what an education for its proprietor and editor was furnished by this active and continuous association with men and things as well as books and literary labor.

Meanwhile, Colburn, after several unsuccessful ventures in other directions, returned to journalism. In July, 1857, *Holley's Railroad Advocate* became Holley and Colburn's *American Engineer*, and in the following September was suspended and never revived. The cause of the suspension appears to have been the "hard times" of 1857; but the ingenuity and energy of the owners made this the occasion of a new venture. Securing from a number of American railway presidents and from private friends the necessary means, they went to Europe, to study foreign railway practice and to report upon those features of it which would be most important at home. This was the first of thirteen journeys across the Atlantic, made by Holley, every one of which was fruitful of benefit to his country. No American ever went abroad more thoroughly furnished for such a work by nature and by training. If Colburn, on this first trip, showed him how to do it, he needed no teaching afterward.

It was on the return voyage that the *Ariel*, in which Holley was a passenger, was nearly wrecked, and obliged to put back. The following vivid description is taken from an unpublished fragment found in Holley's handwriting among his papers:

"We merrily sailed out of the Solent, past the Needles, against a stiffening breeze, just as eight bells sounded the New Year. But the barometer fell and the sea rose for six days, and on the tempestuous morning of the seventh, we were awakened by that joint sensation of ominous silence and new motion. The noisy but assuring heart-beat of the engine-room had stopped, and we were rolling over and over. The paddle-shaft was broken just outside the hull; one wheel was banging against the planking, and likely to go to the bottom with its counter-balancing weight; the ship was in the trough of the sea, and the gale had grown to a hurricane. They tried to make sail enough to get steerage-way, but the fore-yard snapped in two. Then the gallant Ludlow threw out a floating anchor called a 'drag,' a big basin, made of a stout and weighted sail, stretched on four spars. This, with our spanker, held her just so far out of the trough that we only got 'pooped' once—then came in the stern windows, and a foot of water over the cabin floor, washing away babies, furniture and—hope. I knew the engineer professionally, and I crawled down to his den, and begged him to let me do something to occupy my mind, for I was afraid. But he said there was little to do, except to keep the bilge-pump running, for she had sprung a leak. Then I crawled up into the cabin again, and saw some men crying and wringing their hands, and some dear women, brave and quiet, taking hold of each other's hands, and looking like angels. That took away my fear; and I made a sort of nest for some little children who were tumbling about with the *Ariel's* lurches; and I told them stories and worshiped their innocence and their ignorance of engineering which I had spent half a life to learn. So passed the dreadful day and night. We had no regular meals, of course; but the cook scalded some potatoes and himself; and a few of us went into his galley, cooked ourselves and some chops, and in that fun

we almost forgot our condition. The next day was Sunday. The hurricane had not abated. The pumps had simply kept the ship afloat. The greater number of the passengers wanted to have a prayer-meeting, and ask the Deity to stop the storm. There was no authorized representative on board, except a Catholic priest, and he was one of the best and truest men I ever met. He kneeled down in the cabin among us all, and, without any ritual or any Latin, he described our peril and our wants in a few graphic and fervent words, which put us in harmony with the situation. Then the storm broke, and the next morning was bright and sunny. For ten days, we sailed and paddled with our well wheel back to Queenstown."

Colburn and Holley's report—a handsome folio, with 51 engraved plates—appeared in 1858, under the title, *The Permanent Way and Coal-burning Locomotive Boilers of European Railways, with a Comparison of the Working Economy of European and American Lines, and the Principles upon which Improvement must Proceed.* This title is admirable, because it exactly expresses the three-fold nature of the work, which comprises a description of foreign plant and practice, a demonstration of American inferiority, and a recommendation of practicable improvements.

The book reflects much credit on its authors in many ways. With characteristic courage and ambition, they issued it in a style which they could ill afford, and which makes it even to this day one of the handsomest of engineering books. It was a bold venture, even outwardly, and its contents were bolder yet. When we remember that Colburn and Holley were abroad less than three months, collecting the materials for it, we are astonished at its completeness and accuracy. They were "tremendous workers." Holley's letters show that after a few days given to the new delights of travel, and the sights in London, he settled down to intense labor, visiting railway shops and offices, and devoting days and nights to writing and drawing. The excellent descriptions thus prepared, might, however, have fallen unnoticed in the presence of a public little able to appreciate mere engineering details. It was the "Comparison," made by Colburn, which appealed directly and irresistibly to American railway managers—"counting-room engineers," as Holley was wont contemptuously to call them —with its overwhelming demonstration of the financial economy of the best construction and the best machinery. In 1860, Holley wrote:

"The first half of the last decade was distinguished by the *opening*, as if by magic, of thousands of miles of railway; the last half has been distinguished in revealing the fact that the roads thus open are yet to be built."

This revelation was effectually made by Colburn's "Comparison."

It was not enough to show that the annual operating expense of American railways was $120,000,000 against $80,000,000 for the same mileage in England—an excess of $40,000,000; that the annual maintenance of the road-bed cost $33,000,000 here, against $12,500,000 there—an excess of $20,500,000; that the cost of fuel was $18,000,000, against $7,500,000, thus giving as total expenses, $171,000,000 in America and $100,000,000 for the same mileage abroad. Any industrious compiler could present such figures; and the counting-room answer was ready. "Such comparisons could not be made. The conditions were utterly different in the two countries. English lines are very expensively built, and what was saved in current expense was paid out in interest on first cost. The grades were lighter than ours; the traffic was more favorable; there was cheap fuel and pauper labor." This sort of vague *qualitative* talk is what all reforms encounter; and it must be met with *quantitative* demonstration. In all such questions there is "truth on both sides;" but the scientific inquirer weighs the truth, and ascertains on which side is the ultimate overweight. In this case, Colburn proceeded to discuss in detail all the varying conditions, and to give a precise value to each. He showed that of the superior English economy of nearly 60 per cent. in the maintenance of permanent way, only about half was due to favoring circumstances; that of the 44 per cent. superior economy in fuel, only 15 per cent. could be thus explained; that the necessary difference in first cost was far less than had been supposed. By an exhaustive analysis, he tracked the saving to its sources, and proved these to be chiefly the locomotive and the permanent way. This was an argument which financiers could understand. The press took it up, and drove it home. The leading New York dailies came out with long leaders (mostly contributed by Holley) on the causes of the depreciation in railroad property, and drew from this book overwhelming proofs. The English press, of course, rejoiced in its acknowledgment of English superiority. Even the patriotic rage displayed by some of our journals, regarding this conceited attack on American institutions, helped to advertise the book. Taken together with its successor, Holley's *Railroad Practice* (of which I will speak presently), it inaugurated and did much to effect a revolution. As to the completeness of the mechanical part of it (which was Holley's special portion), I may here quote a remark once made to me by a leading railway engineer of this country. Said he, "I keep the book in my office still; and frequently when

inventors call on me with their new ideas about rails, and joints, and sleepers, and boilers, and so on, I open Colburn and Holley, and show them their inventions, already described and discussed."

From Holley's letters during 1858, it is evident that he traveled extensively, soliciting subscriptions from railway companies to cover the cost of publishing the report, and also selling other scientific books on commission to cover his expenses. Probably during this period he made the acquaintance of Mr. Henry J. Raymond, founder and editor of the New York *Times*. His first article in that paper was a vigorous editorial on railway management, published November 9, 1858.

Mr. Raymond was characteristically quick to recognize, encourage, and attach to his corps of editors, reporters, and correspondents young men of talent and ambition He realized that he had found a prize in Holley, who speedily became a frequent contributor to the *Times*. I have found 276 articles from his pen, published in that paper, of which about 200 appeared between 1858 and 1863, and the remainder at rarer intervals to 1875, the last being the leading editorial of April 27, 1875, on the recently appointed United States Testing Board. The range of these articles is indicated by the following classification: Setting aside 52 miscellaneous articles (descriptive, political, etc.), and 30 which may be called "scattering," though devoted to engineering topics, we have 194, divided as follows: Railways (including street railways), 49; steam navigation, 42; war ships and armor, 30; the Stevens battery, 22; arms and ordnance, 19; boiler explosions, 11; and steam engines, 7. The most important and remarkable of these articles were, perhaps, those on the *Great Eastern*, written under the signature of "Tubal Cain." In 1859, he accompanied Mr. Raymond to Europe as a *Times* correspondent, made the acquaintance of Brunel and Scott Russell, and thoroughly studied the structure and details of the great ship. His description (October, 1859) of the vessel and its machinery (accompanied with drawings), his account of the trial trip, the accidental explosion occurring on that occasion, the coroner's inquest, etc., and his discussion of various engineering and commercial questions thus suggested, present a wonderful combination of technical, critical, and literary skill. The articles attracted attention on both sides of the Atlantic, and the *Times* assumed a position of authority on engineering topics not before or since occupied by a New York daily newspaper.

In 1860 Holley again went to Europe for the *Times*, and re-

turned on the first transatlantic trip of the *Great Eastern*. This time his equally remarkable letters were divided between the *Times* and the *American Railway Review*, of which in the meantime he had become editor of the mechanical department. The *Review* was a New York weekly. His connection with it began with its second volume, in January, 1860, and lasted about eighteen months. Among the first things he contributed to it was a description and explanation of the Giffard injector, then a novelty. An examination of the columns of this paper and of the *Times* throws an interesting light on the manner in which he contrived to do so much literary and professional work. He made one hand wash the other. The topics treated for the general public in the *Times* were served up in more technical form in the *Review*. The anonymous editor in the *Times* frequently quoted and commented upon the avowed editor of the *Review*, and *vice versa*. But all this was merely the incidental, though necessary, occupation of this period. He wrote to earn money, and he wrote with the rapidity and versatility of a Bohemian; but all the time his eye was upon his profession, and his articles were but the chips thrown off in the labor of preparing his "American and European Railway Practice," which appeared at the close of 1860. This was, so far as the subject of permanent way is concerned, a digest of the report of Colburn and Holley, but it was a great deal more. The subjects of the combustion of coal, its use in locomotives, the economical generation of steam, the proper construction of boilers, etc., were thoroughly discussed, and the whole problem was treated with the precision of a judge combined with the earnestness of an advocate. The defects of American railway management in these particulars were exposed with satire and indignation. The book was, in even a higher degree than its predecessor, an epoch-making one. Our railway practice in the branches of which it treats has done little more than follow its guidance, and its recommendations and warnings are not yet out of date.

In the preface to this work, Holley acknowledges assistance received from Mr. J. K. Fisher, well known to New Yorkers as an engineer of talent and an inventor who tried hard—and failed—to introduce steam carriages on common roads. In the latter experiment, Holley gave him some professional and financial assistance. The money was lost; but out of this, as out of all other experiences of his life, he drew a dividend of added knowledge. I believe he never ceased to consider the steam carriage and traction engine as

technically an accomplished success, and certain eventually to find a wide use in this country. To discuss the causes which have falsified, thus far, that expectation, and have left us apparently more distant than ever from its fulfillment, would be beyond the limits of this occasion. Suffice it to say, that, in my judgment, the immense extension of railroads is one of them.

Another matter to which Mr. Fisher had given great attention was that of steam fire-engines. How quickly and thoroughly Holley appreciated this problem may be seen in several of his *Times* articles—notably a long one, published December 10, 1858. It is a model of clear and epigrammatic statement, abounding in such sentences as these:

"The size of a fire-engine is limited by the size of the men who handle the hose. We can build an engine that will throw a river over a mountain—*who will hold the butt?*" * * * *

"Boilers which can raise steam from cold water in three minutes can do almost anything else in the next three minutes, if they are not closely watched."

There is ample evidence that the outward rewards of all his labors so far had been mainly in growing reputation, not in money. He was still struggling for a living. In April, 1859, he took out two patents, one for a variable cut-off gear for steam-engines, and the other for railway chairs.

Of the railway-chair patent he writes at the time, "My rail-joint seems to be liked; and I shall doubtless make something out of it." It preserved the continuity of the rail ends by brackets, so attached to the spliced pieces and tension plates that the weight of the wheels of the train on the rail kept the splices tightly in their places, without the aid of plates, nuts, keys, or rivets. It was illustrated in his *Railway Practice*, and in the *Railway Review*. It was tried by one or two roads (I believe with satisfactory results); but it did not come into wide use, partly, as I judge, because reforms in rail-sections and permanent way made the simple fish-plate adequate to all demands. As Holley wrote in the *Review*, "The practical difficulty with the fish-joint is not the form of the fishing-piece, but the form of the rail."

Meanwhile, the pressure of outward necessities continued, but Holley's courage and hope rose to meet it. The denser the medium through which he made his way, the greater his relative buoyancy. In March, 1861, he writes:

"I have an engagement with the publishers of 'Webster's Unabridged Dictionary,' to write a lot of engineering words and definitions, to make some illus-

trations, and to correct engineering definitions, for a new edition of that work, for which I get my name put in the book, and two hundred dollars. The former part of the pay will be pretty valuable, and the latter part very timely in these awful days of panic and poverty. I am at work at this as hard as possible, to get it done in time, and to get the money."

A few days later, he writes, referring to the slow sale of his book, and other difficulties:

"These unexpected hard times have certainly and *fairly* interrupted my plans. Under normal circumstances, things would have come out as I expected they would. Therefore, I do not think it bad management, but bad luck, that I am still in an undesirable position. But I am making my expenses as light as possible, and getting what professional work I can do. I yesterday completed an arrangement with the Camden & Amboy Railroad Company, to alter an engine of theirs to burn coal. I am to be paid eight dollars per day, and to be employed thirty or forty days. Mr. Stevens, the president, has been for some years engaged on a battery for the government, about which you know, of course. He says he shall probably be called on to finish it by this administration, and that he may want to employ me, here and in Europe, for this and other matters. I am also getting some business as an expert, which pays first rate—am writing for the dictionary, and gradually getting the business offered, after which I have so long been seeking. So, on the whole, I do not despair of getting back the money I have been investing for the last ten years in *education*, and of securing something to live on."

Up to this time I find no proof that Holley interested himself specially in politics. He seems rather to have regarded with disgust the manner in which the slavery question, in one form or another, engrossed the attention of Congress, leaving great matters of internal improvement, the regulation of commerce, the safety of travel, the construction and maintenance of public works to be dealt with by crude and hasty legislation. Thus he writes, in the *Times*, May 3, 1860:

"As the law-makers tread the decks of steamers, they will need no expert to unfold the probable causes of danger. Let them but look and tremble; a single compartment with a wooden shell—heaven only knows how weak and rotten—quivering with each stroke of the engine—between them and death; fires roaring and lamps swinging within the very embrace of seasoned combustibles—boiler-plate of questionable tenacity, straining under undue pressure—fire-pumps and hose, bilge-pumps and life-boats, lashed and stowed away for the voyage like so much cargo or permanent ballast; sailing vessels, without light or signal, bearing down into our very path; should such danger overtake us, what are the probabilities of deliverance? The chances are, that there will be a collision—that a hole in any part of the hull will admit the sea to every cranny of the fabric; that the furnace-fires will be quenched before the steam-pumps can be set at work; that the ship will founder before all the boats can be cleared and launched; that all the boats will not hold half the people; that there is no material for rafts; that the vessel will take fire; that the fire will

get the advantage before the pumps can be got at work and the hose adjusted; that the deficient means of overcoming danger, and especially the delay in applying the means provided, will give accident and carelessness the winning start of defense and caution.

"Urgent and reasonable as are the demands of the case, it is found practically impossible to meet them fully and fairly with legislative enactments. Sectionalism, State rights, spoils, corruption, selfishness, and the whole catalogue of personal and party motives and influences, menace alike the interests of the white man and the negro—the African traveler and the Red River slave."

Like the vast majority of our citizens, he did not realize the serious and instant peril of the country. As late as March, 1861, after the inauguration of Lincoln, when the government of the Southern Confederacy under Jefferson Davis had been fully organized, Holley became a candidate for the position of U. S. supervising inspector of passenger steamers. The letters forwarded in recommendation of his appointment to the President were subsequently returned, and after his death I found them among his papers. I do not wonder he preserved them. They constitute an astonishing testimonial to the professional standing of a man not yet thirty years old. A host of firms and individuals, including the presidents and engineers of the principal American railways, and the managers of great shops for the construction of steam machinery, bear witness to the extraordinary ability and fitness of Mr. Holley. If I repeat before this audience the names of J. Edgar Thomson, Erastus Corning, John Taylor Johnston, Sam'l Sloan, Charles Minot, Allan Campbell, S. W. Roberts, Amasa Stone, John C. Cresson, W. H. Clements, David Hoadley, George H. Corliss, J. S. Rogers, M. W. Baldwin, Richard Norris, W. W. Fairbanks, Horatio Allen, Benjamin F. Thurston, Peter Cooper, Abram S. Hewitt, Edward Cooper, J. G. Barnard, William G. Hamilton, Cyrus W. Field, Samuel J. Reeves, Montgomery C. Meigs, to say nothing of College and West Point professors or editors like Henry J. Raymond, and personal friends of the President and cabinet, I need add nothing to prove the unusual force of these credentials. In a private letter dated April 3d, 1861, Mr. Holley says:

"I was in Washington the other day, about the inspectorship, but I do not expect to get it. I have as fine a list of engineering names as could be offered; but I have no hard-working New York City political backers, except Mr. Raymond. Another candidate is more of a politician than an engineer, and he will probably get the place. However, I may get it. I shall certainly *not* go and bore the President and departments. If they can't take my papers as evidence, they ought not to take my own statement."

Those who remember him in the brightness of his youthful prime cannot but feel that his personal application, adding magnetism to the weight of his professional indorsements he presented, would not have bored even the tired officials at Washington, but would have inspired them with the desire to win for the public service his skill and enthusiasm—would have enabled them to find delight in duty. But it was not thus to be—and so far as we can now discern, what was to be was better.

The letters of those gentlemen I have named, with many others, were subsequently recovered from Washington, and arranged and filed by Mr. Holley. On a blank page at the end, he wrote in his bold hand these significant words: "What came of it? Mr. Holley was not appointed." Yet through all his life he was proud of the indorsement he had thus received; and to-night we may safely say that those who gave it need not be ashamed.

Besides the ordinary fatuity which presides over governmental appointments, and the special pressure of party politics in the case of a new administration, receiving the powers and privileges of federal office for the first time from the hands of its party opponents, there were in this instance peculiar reasons for the apparent neglect of Holley's application. Events were then occurring which might well cause those in power to overlook the inspectorship of steamboats. The attention of all was concentrated, not upon the possible accidents that might occur to vessels navigating the Hudson or the Sound, but upon the events then taking place in the South. The firing upon our flag in Sumter and Baltimore excited to the highest pitch the feelings of the North. Many of you must remember the scenes that transformed the metropolis: the vast meeting at Union Square, with its many platforms and orators, and its surging, shouting multitude of hearers and spectators. What enthusiasm attended the passionate appeal of Mitchell and Baker, as they pledged their lives to the service—pledges redeemed by both, after a few short months, in blood! And what a frenzy of applause followed the reply of one of the orators, when being asked from the crowd, "How about the Seventh Regiment?" he answered, "They have just been heard from by telegraph at Philadelphia. It is proposed that they go by sea to Washington; but *they prefer to march through Baltimore!*"

The sudden change in the sentiments of many who up to that time had hoped for compromise, is well illustrated in the case of Holley. In January, 1861, he had written:

"I suppose we have got to have a war; but it is a pity to fight for what isn't worth fighting for. It seems our duty to have a general convention of the people and let the beggars go."

But the events of the next three months were for him, as for the majority of his Northern countrymen, a rapid political education, and on the 23d of April, 1861, he wrote to Secretary Chase the following letter, substantial duplicates of which were sent to the War and Navy Departments also:

"I am an applicant, indorsed by a large number of prominent engineers, for the office of United States Supervising Inspector of Steamers.

"In the present state of affairs, I am anxious to bring such engineering facilities as I may command into the service of the Government.

"I have an intimate acquaintance with Mr. Scott Russell and many other English engineers and ship-builders, having been sent to Europe several times on engineering business.

"If I can do the Government any good with reference to the construction or purchase of ships or arms, the construction of batteries, gun-boats, or iron vessels of light draught, the application of armor to ships, etc., I hereby offer my services, *without compensation*, desiring only that my necessary expenses be paid, as I have not the money to pay them.

"I know that I have peculiar facilities for gaining the latest information relative to the construction of iron ships and boats and their engines, without waste of time.

"I refer you to the names appended to my application aforesaid. I am ready at an hour's notice."

On the same sheet, Mr. Raymond added these words: "I know Mr. Holley *intimately*, and know him to be in every respect one of the very best men whose services the Government can command.

From another source, I learn that at this time Mr. Holley was ready—as what patriotic young American was not?—to enlist in the Army or Navy, but that a little reflection convinced him of the greater usefulness which lay in his professional skill.

The letter I have quoted was filed at the Treasury Department (as the clerical indorsement upon it shows) together with the other papers concerning Mr. Holley's previous application for office. Neither it, nor the similar letters addressed to the Navy and War Departments, were ever acknowledged. Probably there was no time in those crowded days for mere politeness and thanks. Probably thousands of other men were tendering their services, even without pay. Moreover, experienced administrators know very well that the acceptance of such gratuitous service is in most cases no advantage to the public. Officers under salary, and no

others, can be held to strict responsibility. The honorary employees of the State demoralize the rest. They despise red tape, which is, on the whole, essential, however harmfully it may now and then be tangled; and, to speak plainly, no tangle is so mischievous as that produced by a volunteer shuttle, flying lawlessly across the web of a regular system. Railroad engineers know how many trains must be delayed when some swift "special" demands the track, in spite of the time-table.

Doubtless these calm considerations did not comfort the soul of the ardent young volunteer, conscious of the power he freely offered to his country. There is a touch of bitterness in the words indorsed upon the papers I have quoted: "What came of it? The letters received no attention. The foregoing application to Secretary Chase was found filed with the application for the Inspectorship, at the Treasury. The End." To which, indeed, History adds, "Not the end, but the beginning."

Both his patriotism and his professional ability found an immediate object in the Stevens battery, and in other plans which Mr. Edwin A. Stevens proposed to the government. That remarkable man and his brother, Robert L. Stevens, were the originators of most of the modern improvements in naval warfare. Their father, Col. John Stevens, built in 1805 a steam-vessel with twin screws—a feature adopted in the Stevens battery, and in the *Naugatuck* (a vessel presented the U. S. Treasury Department during the war by Edwin A. Stevens), and subsequently employed in the war-ships of England. The armored iron-clad known as the Stevens battery was proposed by the brothers Stevens to the United States Government as early as 1841. It was not until 1854 that the work was commenced; and in 1861, twenty years after its suggestion, it was still unfinished, the Government having refused for more than eighteen years to do anything about it. Half a million of public money had been spent upon it; Mr. Stevens had spent $200,000 besides; and he now asked from Congress an appropriation of $500,000 to finish the whole work. The proposal met with unexpected opposition. Holley states the case in a *Times* editorial, August 13, 1861, as follows:

"Here is an iron screw-ship of 6,000 tons, made of the best selected material, with as beautiful a model as ever floated, with engines and boilers of a pattern superior to that of most modern steamers, and capable of developing the whole horse-power of the *Great Eastern*, and a speed of twenty miles an hour—a ship that can turn on her own center in perhaps a minute—outrun any known enemy, fire with her eight guns a heavier broadside than the *Warrior*—fire three of these

guns at a time parallel to the keel—sink to the gun-deck during the action, and so only leave her cover, as it were, to be protected by plates—carry 6½ inch armor, inclined at 30°, and coal enough to cross the Atlantic at ordinary speed—a ship up to the best commercial practice in every important detail, and ahead of the best naval practice in nearly all—and this is the vessel that some of our contemporaries advise the Government to abandon as a *failure*, while Congress debates bills for the construction of *modern* iron-clad ships!"

It is impracticable on this occasion to trace the course of the discussions, examinations, reports, negotiations, and intrigues which constitute the subsequent history of the Stevens battery. Holley's work, in connection with it, turned out to be rather literary than technical. Mr. Stevens, whose age and health disinclined him to engage actively in a fight for the privilege of serving his country with his knowledge and experience, left this part largely to Holley, who wrote memorials, arguments, criticisms, editorials, with untiring zeal, bringing to bear science, wit, eloquence, and anger in a manner peculiarly his own. Whatever may be said of Stevens' battery, Holley's battery was unquestionably a powerful one; and, so far as words could win the battle, he won it. But the victory cost too much time, and when won, it was fruitless.

The peculiar features of the Hoboken ship have been elsewhere adopted, and in turn superseded. The principal effect of this episode upon Holley's career was the attention it caused him to give to the subject of ordnance and armor.

Sent abroad in 1862 by Mr. Stevens to investigate this subject, he found the facts he needed scattered in official documents, monographs, unpublished records, etc., and speedily his own note-book became a more comprehensive and accurate collection of them than any printed book. He obtained his information with some difficulty. I find, for instance, the following letter from his friend, J. Scott Russell, referring to certain ordnance works or experiments of the British Government:

"My Dear Holley: "Sept. 24, 1862.

"I have applied in the proper quarters, and find that special instructions have been given that *you* are to be refused admittance.

"As you have achieved this distinction, you will, I am sure, have no wish to put yourself in a false position. * * * Yours sincerely,

"J. Scott Russell."

On another occasion, Holley desired to study the lines of a new British iron-clad, then in process of construction. One of the contractors, whom he had made (as usual) first an acquaintance and then straightway a friend, said to him, "If you can manage to get

into the yard, I will show you all you want to see. But I am powerless to procure admission for you, and I am sure it will be refused if you ask it." It must be admitted that in spite of the confidence of his friend, Mr. Scott Russell, Holley did, on this occasion, "place himself in a false position;" for he hired a stylish carriage, arranged himself in solitary state with folded arms on the back seat, gave the necessary instructions to the coachman, and drove straight through the big gate in the yard, acknowledging with a bow the presented arms of the guard, as proudly as any other Lord of the Admiralty. Once inside, he found his friend, and satisfied his curiosity. This story, now published for the first time, is respectfully dedicated to her Majesty's Government!

We can hardly wonder at the occasional exclusion of Holley from important works at that time. He was certain to send to his own government whatever new facts he observed. On the whole, however, he was treated with liberality, and his note-book became, at the close of 1864, a treatise on Ordnance and Armor.

This work has, perhaps been overrated. It is in reality a clever piece of book-making, remarkable as showing with what rapidity and accuracy a trained reporter, employing both pen and pencil, can collect and arrange a mass of data. Holley's independent criticisms and suggestions are not made prominent; though, when they occur, they are sensible and timely. The book is simply an attempt on his part to supply the need which he had felt on approaching the subject of ordnance and armor—the need of a summary of the existing state of the art. It was translated into French, and became everywhere a recognized authority—just as a dictionary or a directory is recognized authority, particularly if it is large and thorough, and intelligently arranged, and the only one to be had. It is out of date now. The arts of warfare have made great progress since it appeared; and though it is still indispensable as a record, it is, to me at least, chiefly interesting as a specimen of Holley's method of work; his ability to grasp the leading principles of any mechanical problem; the facility with which he seized the details of an apparatus or an experiment, putting them down for future reference in words or in sketches, as might be most convenient; and the system with which he indexed everything he had once noted, so that he could at any moment recur to it again without delay.

While he was thus studying ordnance and armor, the columns of the *Times* coruscated with brilliant articles from his pen on these

topics, and the bureaus at Washington had frequent reason to regret that his genius was not directly enlisted in their assistance, instead of employing the free lance of destructive criticism.

An interesting and able summary of this subject appeared in the *National Almanac* of 1863, under the title, "Iron-Clad War Vessels;" and the *Atlantic Monthly* of January, 1863, contained an article from his pen on "Iron-Clad Ships and Heavy Ordnance." At the close of this article, he speaks of a more extended work, about to be published by Van Nostrand, of New York, thus showing that at that time Ordnance and Armor was almost completed, though it did not publicly appear for nearly two years.

Before it saw the light, his activity had turned into a new and still more important channel. In May, 1863, he writes:

"It is a matter of regret to me, on many accounts, that I have to go to England again this summer; but this is no pleasure trip, but a trip preparatory, I hope, to something settled. Precisely what I am going for, I am not at liberty to say except that I am going to get information for Corning Winslow & Co., about a new manufacture. If I succeed, they are going to establish the business, which will be in nature allied to, but in a business way separate from, their present manufacture. **They then wish me to become a partner in the new business.** * * * and expect, if I succeed, to spend about $30,000 in establishing the new manufacture."

Imagine starting in the Bessemer business with $30,000!

His mission was successful. The Bessemer patents were purchased, and subsequently combined with the conflicting American patents of Kelly. The works at Troy were built and started in 1865, and enlarged in 1867. From this time on, the career of Holley was substantially the history of the Bessemer manufacture in the United States. In 1867, he built the works at Harrisburg. About a year later, he was recalled to Troy, to rebuild the works there, which had been destroyed by fire. Still later, he planned the works at North Chicago and Joliet, the Edgar Thomson works at Pittsburg, and the Vulcan at St. Louis, besides acting as consulting engineer in the designing of the Cambria, Bethlehem, and Scranton works.

It is not my purpose to describe in detail the improvements he introduced into the Bessemer plant. They have been admirably summarized by Mr. Robert W. Hunt, in his paper (Trans. Am. I. of M. E., Vol. V., p. 201) on the History of the Bessemer Manufacture in America. It is fair to say that they put an entirely new face on the commercial relations of that manufacture, by enormously increasing its productive capacity, and proportionately decreasing

its cost. Whoever would appreciate their nature and effect, need do but two things: First, compare the pictures of the Bessemer plant and its arrangement, as given in English text-books and journals of that period, with the plans of American works; secondly, compare the records of foreign works with the records of our own. Mr. Hunt says:

"The result of his thought gave us the present accepted type of American Bessemer plant. He did away with the English deep pit, and raised the vessels so as to get working space under them on the ground floor; he substituted top-supported hydraulic cranes for the more expensive counter-weighted English ones, and put three ingot cranes around the pit instead of two, and thereby obtained greater area of power; he changed the location of the vessel as related to the pit and melting-house; he modified the ladle-crane, and worked all the cranes and vessels from a single point; he substituted cupolas for reverberatory furnaces; and last, but by no means least, introduced the intermediate or accumulating ladle, which is placed on scales, and thus insures accuracy of operation by rendering possible the weighing of each charge of melted iron, before pouring it into the converter. These points cover the radical features of his innovations. After building such a plant, he began to meet the difficulties of details in manufacture, among the most serious of which was the short duration of the vessel-bottoms, and the time required to cool off the vessels to a point at which it was possible for workmen to enter and make new bottoms. After many experiments, the result was the Holley vessel-bottom, which, either in its form as patented, or in a modification of it as now used in all American works, has rendered possible, as much as any other one thing, the present immense production."

Concerning the increasing productiveness of the American Bessemer plant, it may be said in round numbers that it has been raised from the capacity (per two converters) of about 900 tons per month to more than 10,000 tons for the same period—an exceptional maximum of over 14,000 tons of ingots in a single month having been reached by the Edgar Thomson works. Holley's arrangement of buildings and machinery, to secure convenience in handling materials, and his movable converter-bottom and other devices to reduce the time lost in repairs, were undoubtedly the basis of this great advance, though valuable contributions have been made by the able engineers who followed his lead.

But turning for a moment from technical details, I cannot forbear quoting from an article written by Holley, in 1865, for the Troy *Daily Times*, the description of a Bessemer "blow" at night. It is not only admirable in itself, but interesting as a proof of his keen perception of the picturesque and artistic elements in his profession:

"The cavernous room is dark, the air sulphurous, the sounds of suppressed power are melancholy and deep. Half-revealed monsters with piercing eyes

crouch in the corners, spectral shapes ever flit about the wall, and lurid beams of light anon flash in your face as some remorseless beast opens its red-hot jaws for its iron ration. Then the melter thrusts a spear between the joints of its armor, and a glistening, yellow stream spurts out for a moment, and then all is dark once more. Again and again he stabs it, till six tons of its hot and smoking blood fill a great caldron to the brim. Then the foreman shouts to a thirty-foot giant in the corner, who straightway stretches out his iron arm and gently lifts the caldron away up into the air and turns out the yellow blood in a hissing, sparkling stream, which dives into the white-hot jaws of another monster—a monster as big as an elephant, with a head like a frog, and scaly hide. The foreman shouts again, at which up rises the monster on its haunches, growling and snorting sparks and flame.

"What a conflict of the elements is going on in that vast laboratory! A million balls of melted iron, tearing away from the liquid mass, surging from side to side, and plunging down again, only to be blown out more hot and angry than before—column upon column of air, squeezed solid like rods of glass by the power of five hundred horses, piercing and shattering the iron at every point, chasing it up and down, robbing it of its treasures only to be itself decomposed, and hurled out into the night in roaring blaze.

"As the combustion progresses, the surging mass grows hotter, throwing out splashes of liquid slag; and the discharge from its mouth changes from sparks and streaks of red and yellow gas to thick, full, white, howling, dazzling flame. But such battles cannot last long. In a quarter of an hour, the iron is stripped of every combustible alloy, and hangs out the white flag. The converter is then turned upon its side, the blast shut off, and the recarburizer run in. Then for a moment the war of the elements rages again; the mass boils and flames with higher intensity, and with a rapidity of chemical reaction, sometimes throwing it violently out of the converter-mouth; then all is quiet, and the product is steel—liquid, milky steel, that pours out into the ladle from under its roof of slag, smooth, shining, and almost transparent."

It is scarcely possible to exaggerate the importance, to this country and to the world, of the Bessemer manufacture, and particularly of that manufacture on the vast scale which Holley's improvements helped it to assume. The end is not yet. The structural uses of steel are still in their infancy. But in one branch of engineering—the branch of Holley's early choice and love—a world-shaking revolution has been accomplished. The permanent way of which he wrote so much has received its final perfecting touch in the steel rail—and cheap transportation has been the result. The farmers and cattle-breeders of Great Britain find themselves brought into competition with regions of the very existence of which they had scarcely heard before. The invention of an English chemist, perfected and applied in America, reacts upon the whole social fabric. The gigantic specter of the land question itself reveals through its dread garments a skeleton of Bessemer steel!

To Holley personally, the entrance upon these new labors was the greatest change of his life. His chance, for which he had so patiently waited and so thoroughly prepared himself, had come at last. His work changed from the critical to the creative; and a whole side of his genius, repressed hitherto, sprang into joyous power.

All his life he had been fond of designing. The fertility of his imagination and his artistic taste were shown in a thousand ways—in the drawings with which he adorned albums and scrap-books; in the design he made for the charter-oak chair of state, which still wins admiration in the Capitol of Connecticut; in his love of old cathedrals and masterpieces of painting and sculpture. But he was not bewitched by the surface of beauty alone. Looking below the surface, he recognized the beauty of adaptation. He recognized the great scientific truth that the line of economy is the line of grace. The arch, the truss, were no unmeaning forms to him. And beneath a strong, light roof, or before a well-designed machine, or in the midst of a well-arranged plant, he found the satisfaction of an artist as well as an engineer. I think he took more pride in the Edgar Thomson works than in any other which he helped to build, because, as he once said to me, he began at the beginning with them, taking a clean sheet of paper, drawing on it first the railway-tracks, and then placing the buildings and the contents of each building with prime regard to the facile handling of material; so that the whole became a body, shaped by its bones and muscles, rather than a box, into which bones and muscles had to be packed.

Yet this new activity was not substituted for the older ones; it was rather superadded to them. In January, 1869, he took charge of Van Nostrand's *Eclectic Engineering Magazine*, which he edited for a year. In August of that year, he wrote from Troy:

> "I have not got along far enough in life to look back on much work or much fruit from it; but I have lived long enough to conclude with certainty, that leisure is the hardest thing in life to get along with. I try to have as little of it as possible."

In the subject of technical education, as I need not tell the members of these societies, he was deeply interested. Elected in 1865 a member of the Board of Trustees of the Rensselaer Polytechnic Institute, he made his influence felt in favor of an improved curriculum, keeping pace with the demands of the times. While it is impossible to discuss at this time the views on technical education which he subsequently announced, it is worth mention, in passing,

that the system he so eloquently advocated, of a practical training preceding the scientific instruction, was not the one under which his own genius had developed itself. He went from the school to the shop, not from the shop to the school.

If I pass swiftly over the latest and most fruitful years of his life, it is not because I fail to recognize their importance. They were in every way his best working years. His rapidly growing fame, his widening circle of friends, his own matured power, combined to give value to his labors, and to win for them adequate reward. In fact, this is the answer to those impetuous ones who think it better, as they say, "to wear out than to rust out," and declare that if they do twice as much, and live only half as long, the world at least will be no loser. This is not true. A true man's last work is his best. Two bushels of green apples to-day are not the adequate substitute for one bushel of ripe ones, when Time shall have brought them to perfection. And this ripening effect of Time is in human character the one thing that cannot be hurried. Wisdom —the degree conferred upon faithful students in the University of Life—cannot be had in the sophomore year.

But the work of these wisest and intellectually strongest years of Holley's life, is, for the most part, either familiarly known to all of you, or it is still under the lock and key of his professional relations, in confidential reports. His papers and addresses in the Institute of Mining Engineers, of which he became a member in 1872 and President in 1875, the Society of Civil Engineers, of which he was a Vice-President, in 1876; the Society of Mechanical Engineers, of which, together with the honored chairman of this meeting he was the founder, and the British Iron and Steel Institute, and Institution of Civil Engineers, of which he was a member; the admirable paper on "Iron and Steel," contributed by him to the Reports of the Judges of the Centennial Exposition in 1876; the series of illustrated articles on American iron and steel works, prepared by him together with Mr. Lenox Smith for London *Engineering* from 1877 to 1880; his masterly treatise on "Steel," published in 1880 in Appleton's Cyclopædia of Mechanics; and, in another sphere, his breezy description in *Scribner's Monthly* for May, 1878, under the title "Camps and Tramps about Katahdin," of a health-giving summer excursion, in genial artist company, to the forests and mountains of Maine—these are both familiar and accessible to you all. But more voluminous, and in many respects still more valuable, were the reports which he printed and issued confidentially to his

clients (for the last five years to the members of the Bessemer Association only) on the various branches of steel manufacture. No doubt when the immediate business value of these reports shall have passed away, they will become accessible to engineers generally; and they will be found a mine of clear, precise, well-arranged, and well-discussed information. I know that he regarded them as his best work, and that he put his life into them.

Of all the later labors to which I have alluded, and of other works of his pen, I shall publish as an appendix to this address a catalogue,* which I believe is complete, and which in itself constitutes a striking picture of his intense and various industry.

It was probably about 1875 that his elastic strength began to fail. In that year he wrote: "I have been so hard at work for so long that I am getting pretty tired and played out. I am going in a week to one of the Elizabeth Islands, off New Bedford, where there is neither mail nor telegraph, to lie on the sea-shore for a week, and try to get strong and *sleepy*." That last word tells the story.

In June, 1875, he was appointed a member of the United States Board for Testing Structural Materials. He had been unweariedly active in promoting the formation of this Board; he was not the least laborious of its members; and, down to the end of his life, he ceased not to strive that his work, so promising, so fruitful, so unfortunately interrupted, should be revived and continued. In our endeavors to advance that great work against ignorance, indolence and prejudice in quarters high and low, we shall surely miss henceforward his voice and pen.

In 1879 he accepted an appointment to lecture at the School of Mines, Columbia College, on "The Manufacture of Iron and Steel." He wrote these lectures with great care, printed a complete synopsis of them for the use of the students, and took as much pains to assure himself of the proficiency of his class, by rigorous examinations, as if he had been a resident professor, and this his chief business.

Besides the two early patents which I have already mentioned, Mr. Holley obtained fourteen others. Ten of these refer to his improvements in the Bessemer process and plant; two of them to roll-trains and their feed-tables; and the remaining two are those of July 8, 1876, and March 1, 1881, the first for a water-

* This catalogue will be published in the "Memorial Volume."

cooled furnace roof, and the latter for a steam-boiler furnace, with gaseous fuel. These are both important; and the first of them, in which the pipes cooling the arch of a furnace constitute at the same time the skeleton supporting it, is highly ingenious in conception and detail. It is not unlikely to be the "furnace of the future" for many purposes. The last of his Bessemer patents (purchased since his death by the Bessemer Association), that of the detachable converter-shell (April 26, 1881), is perhaps the most important of all, after the old converter-bottom patented August 9, 1870. I will not describe it here. It is discussed by its inventor in a manner to leave nothing more to be said, in a paper read in November, 1880, before the American Society of Mechanical Engineers.

It is pleasant to remember that in these later years he began to receive the public and professional recognition which his genius and perseverance deserved. In 1878, on the twenty-fifth anniversary of his graduation, his Alma Mater bestowed on him the honorary degree of Doctor of Laws. A still more appropriate honor, the Bessemer medal, given in cordial though late appreciation of his services and merits, can be placed, not alas! in his hand, but only on his tomb. But these things are but trivial symbols of the warm, unanimous, universal love and respect with which he was regarded by the engineers of two worlds.

This has been more adequately shown by the outburst of sorrow and of eulogy on both sides of the Atlantic, which followed his death. Yet scarcely less significant was the cordial welcome which, while he yet lived and labored, awaited him everywhere on his journey. All doors—even those which were inscribed with "No admittance"—opened before him. One of his friends who has been traveling this year among foreign iron and steel works, writes that Holley's name has been everywhere a potent charm, securing for him an eager courtesy of reception.

I have resolved to make this address, as far as may be, purely professional and critical; and there has been no lack of testimony to Holley's private virtues and personal magnetism, so that I need not dwell at length upon these. But even in a cold estimate of his professional achievements, these qualities cannot be passed over. Generosity, honor, tact, unselfish interest in the welfare of others, high devotion to great causes, unstinted service to the interest of employers, a full performance—nay, an overflowing performance—of every duty; these qualities win love and trust;

and to win love and trust, in our profession, as in every other, is the very heart of success.

We may answer now the questions with which we began. This life *was* successful. It was filled with the joy of labor; it was surrounded at the last with comfort and fame and troops of friends. But the success was not of accident, or luck, or sudden growth. It was earned, inch by inch; won out of innumerable delays and defeats; held at the cost of constant vigilance and toil. Homer sings of warriors who were invulnerable and irresistible; but Homer gives them the assistance of the gods, fighting invisibly beside them; and to my mind, his noblest heroes are those who stand up bravely against such odds, and die where they stand. Again, the tales of chivalry are full of triumphant champions, whose lances in *melée* or tourney nothing can resist. But history tells us that, apart from the exaggerations of the legend, these all-conquering heroes were arrant humbugs—princes, whose prowess it was the part of courtiers to help them to exhibit; that their invariable triumph was the farce of hired players. *Our* hero was no such gay cavalier. Neither miracle nor connivance made his lance omnipotent. His armor was bruised and dented in earnest; he knew the shock, the overthrow, the retreat, the struggle again and again renewed, the victory that called for new conflicts with new risk of defeat.

If Holley's genius was such as to forbid us from hoping by mere effort to attain equal heights, yet, on the other hand, there is ample encouragement and instruction in his career for all young engineers. Let me, in closing, barely mention its chief lessons.

The first is the great benefit of uniting theory and practice. It is less important how these are to be combined than that the student of either should not despise the other. Every word that Holley spoke, every line he wrote, betrayed his familiarity with the practical operations, tools, difficulties, and needs of his business. A great inventor once said to me (when I talked to him of some fancied discovery of my own): "My boy, half the art of invention consists in knowing what needs to be invented." Holley's career illustrates this principle, and bears witness, also, how deeply he felt what he called the inadequate union of engineering science and art, and how ardently he labored to make it closer and more complete. Not his eloquent words merely, but the eloquence of his whole life speaks one language—the language of the brotherhood of brain-workers and hand-workers. And what he was, even more

than what he said or did to promote such union, wrought mightily to that great end. For the end is to be found in the multiplication of such men as he—men who do not merely preach harmony to the two classes, but actually belong to both.

It is important to observe that the foundation of his training was wholly American. Far be it from me to disparage the advantages of foreign study. I would not speak such treason to my own Alma Mater in a far land. But I say without hesitation, that he brings most from travel and study abroad who carries most to them. Many a precious graft they have furnished, and will yet furnish, to our native stock; but the stock is as important as the shoot, and there are too many young men returning with their hands full of scions and nothing to graft them on. How illustriously different was Holley's career!

Another important matter is the early cultivation of the observing powers, and, as incidental thereto, the art of drawing. Holley's facility in these respects was an inestimable advantage to him. He inclined to graphic methods of stating and solving engineering problems; and his eye, thus trained, became an intuitive judge and calculator.

Then comes, in natural succession, the habit of instant, rapid, accurate, methodical recording of observations. It was Holley's practice to do this constantly; to make every record so clear and complete that it could be comprehended and used after years had passed; and to index his note-books and scrap-books so that they became thoroughly available at any moment. This is no trifling matter. When the officers of our Corps of Engineers are examined as to their fitness for promotion, they are obliged not only to answer questions and prepare "projects," but also to exhibit the note-books they have kept during their terms of service. No other revelation of character is more significant, no test more severe. The work that a man does in a hurry, and unobserved, and for himself, not the public, tells the story of his method and temperament. Holley's note-books are models of fullness and order.

But neither observing, nor recording, nor studying, nor the combination of all these with practical training, completely furnish the engineer for the highest place. For he has to deal, not merely with matter and mathematics, but also with men. They must be made to recognize his skill, to back his enterprise, to coöperate in his achievements. Influence, *influence*—that is the secret of power.

Genius may seize opportunities; influence brings them. And the chief vehicle of influence is language. The mastery of language, therefore, is no superfluous accomplishment to the engineer. The young man who deliberately and of choice says, "I mean to be scientific, but not 'literary;'" or the parent who says, "My boy is not going to need a liberal culture; he is going to be an engineer," is ignorant of the most potent principle of modern life—the solidarity of the race, the dependence of each upon all, the necessity of a wide foundation for a high fame, the universal law that every occupation deals ultimately with men even more than with things, and that the ability to shape things is almost barren without the power to move men.

But language, as the means of this power, is effective in proportion as it is filled with appeals to the responsive associations of human minds. A host of things in fancy, poetry, history, and general literature, concerning which people are interested, may be trivial in themselves; it is nevertheless worth while to know them and to use them, as a means of commanding the interest and assent of men. In other words, a wide culture, in sympathy with the age in which we live, is an element of power. It is true that all this, belonging to the art of expression, is wasted in the hands of him who has nothing to express. Men may be arrested to listen, but they will soon find out that behind the skillful utterance there is neither character nor knowledge.. They may be fascinated by the instrument, until they find out there is nothing in the tune. But when real genius and noble ambition utter themselves through the channels of art in language, how gladly hears the world!

Holley's versatility and intellectual sympathy with many lines of thought prevented him from sinking to the level of drudgery, though he worked harder than many a drudge; they made him not merely a bricklayer, but an architect for his generation. Controlled and reinforced by a mighty perseverance, softened and brightened by an unfailing gentleness of soul, they added to his genius that which made him great. For what we call greatness in any sphere is simply *recognized excellence*. The excellence may be spurious, the recognition may be factitious and ephemeral—then the greatness is false, and the great of to-day are forgotten to-morrow. But when a noble character has been nobly exhibited, when genuine power has won genuine praise, when fame soars not for a brief flight into the windy air, but stands firm-footed on the solid pyramid of achievement, to sound through her silver trump

the name of her victorious son—conqueror of nature, leader of men —this greatness will endure.

Build him a monument that shall testify our love and his renown. Let the world understand that not alone the plots of politics or the luck of war may give title to such public memorials. This witness, addressing as it does the imagination, the ambition, the worthy pride of the greatest number of men, is conspicuously appropriate to a life so many-sided and complete, so simple and sincere, yet so popular and influential.

He did not, as once he feared he might, go down poor and unknown, carrying with him thoughts of which the world was not worthy. He was heard, believed, accepted, rewarded—with no greater delay or difficulty than sufficed to bring out to their full extent his own best powers. It was given to him to do grand things in the sight of all men. And beneath all our words and pictures and statues of him lies forever a sure foundation—the work that he did for his time.

Foresters tell us that a tree once marked will retain the mark, though a hundred years of growth may have overlaid it with later coverings. What may be the future spread and stature of the stately oak of American engineering we cannot presume to foretell. But there will come no time when the historian, stripping off the rugged bark, and cutting through the rings of many generations, will not find at the heart that name which with keen blade and skillful hand was carved by Alexander Lyman Holley!

THE MECHANICAL ENGINEER—HIS WORK AND HIS POLICY.

THE PRESIDENT'S ANNUAL ADDRESS.

BY

ROBERT H. THURSTON, HOBOKEN, N. J.

GENTLEMEN OF THE SOCIETY:—LADIES AND GENTLEMEN:

It is with mingled feelings of pleasure and of regret that I appear before you, for the third time, to deliver the formal opening address at the annual meeting of the American Society of Mechanical Engineers.

I have to express, inadequately as I may, my sense of the honor accorded me and my appreciation of that kind feeling and of that confidence which placed me in this chair as your first President, and to-day particularly, my gratification that, after conferring that distinction for another term, both officers and members have so kindly and effectively upheld me in the effort to secure a firm and permanent basis for future usefulness for this Society.

In retiring after two and a half years of service, I have the proud satisfaction of being able to look back upon an initial period in the history of the Society which is, perhaps, unexampled, and I gladly fall back into the ranks of a body which already numbers 350 members, and which includes in its list nearly every distinguished engineer in the country as well as a large number of the younger and brighter minds now coming forward to do our work—a Society which boasts on its list of honorary members the greatest engineers of Europe.

In the first of my two earlier addresses I attempted to lay before my audience a concise statement of the character of this organization, the objects proposed to be attained in its formation and by its action, and the principles which I conceived should guide it, as a body, as well as its members individually, in their efforts to further those objects.

In my second annual address I endeavored to indicate what progress had been made, and what stage had been reached, in the various arts which constitute our department, and to show what direction our steps are now taking and what are the needs of the time so far as they concern the mechanical engineer. I pointed out

what seemed to me the more important problems presenting themselves for solution, and stated what were apparently the most promising directions in which to seek results.

I finally called attention to the relation of technical instruction, and of systematic training in the arts to our profession, and urged the supreme importance of making, promptly, the most energetic efforts to inaugurate a general and complete scheme of public and private education.

In this, my third address, I propose to review very briefly the work of the mechanical engineer up to this date, to present a concise summary of what has been accomplished, and to again examine the line of progress with a view to ascertaining more exactly than before in what direction our labors may be most profitably directed in the near future. Nature rarely turns a sharp corner in any of her great movements, and the direction of our progress may be expected, in the immediate future, to be very nearly what it has been in the recent past. Newton's laws hold as well in sociology as in mechanics.

Finally, I propose to touch upon those great social problems which concern the engineer even more than our fellow-citizens, not simply because he has to deal more directly with them, as an employer and a director of labor and of capital, but, principally, because it is his province, his duty, his privilege, more than that of other men, to study and to solve them, and to inaugurate and carry to completion all those great measures to which their solution leads.

MATERIALS.

In the handling of metal, we have still much to learn. The weakness of the large sections of metal necessarily used in our heavier work still remains a serious evil, and our inability, especially when using steel, to secure the highest tenacity of the metal is a standing reproach to our profession. I have had occasion to test hundreds, yes, thousands, of samples of iron and steel during the last few years, and have never yet found a maker able to give equal tenacity in large and small sizes. The difficulty seems particularly serious in dealing with forged iron built up of scrap and with heavy sections of any kind of steel. I find iron carrying 75,000 pounds per square inch in No. 8 wire, 55,000 in inch bars, and falling to 40,000, or even 35,000, in heavy engine-shafts and beam-straps. Steel varies still more seriously. It is to be hoped

that, with the more general use of ingot metal, the introduction of hydraulic forging and of improved methods of heating and handling, so as to avoid the introduction of many small parts in building up large masses, or frequent exposure to high temperatures in the process, this element of cost and danger may, in a measure at least, disappear.

The great testing machine at Watertown Arsenal is constantly at work, under the direction of Colonel Laidley, sometimes for private and sometimes for public benefit, and has already done some extremely valuable work in that important and unexplored field—the investigation of the strength of large sections and parts of structures. Its most valuable work is done intermittently and its usefulness is far less than it should be, and would have been had its original purpose been adhered to. There seems no immediate prospect of the resumption of the great work organized in 1875, and planned and commenced by the Government Board.

The petitions of this Society, of the Society of Civil Engineers, of the Institute of Mining Engineers, of the Iron and Steel Association, of the faculties of the leading technical schools and colleges of the United States, and of business men and other private individuals of all classes, with all the influence that they could command, separately or collectively, have been inadequate to secure the restoration of that Board, or the creation of a similar organization, or the resumption of the great work barely planned and begun by the old Board.

This fact is as suggestive of the necessity of a movement on the part of the business men of the country for the purpose of securing some influence in its government, as it is remarkable as illustrating their utter impotence to-day. Meantime, the Ordnance Bureau of the Army has a small appropriation for use in this direction and we shall look with hopeful interest for results.

But "Iron, tough and true, the weapon, the tool and the engine of all civilization," as Theodore Winthrop calls it, is now fairly displaced by its younger rival, "*mild steel*," or, more exactly, "ingot" or "homogeneous" iron.

For all shapes that can be rolled, this revolution is accomplished; and, in forged work of small size, the change is hardly less complete. This is especially true of railroad work, and not only rails, tires and axles, bolts, rivets and boiler plate are becoming common in steel, but piston and connecting rods, all forged parts of the valve gear and minor parts of the engine, are now made in this tougher, stronger, and more uniform and reliable metal.

The introduction of the basic process—tardy as it is—by cheapening the stock of the steel maker, and the steadily increasing familiarity of makers and users with the characteristics of the new metal, and with the requisites for successful manufacture of demanded grades and better qualities, will undoubtedly, before many years, make its use so general that puddled and forged iron will become almost or quite unknown in our art. The growth of pneumatic steel manufacture in this country during the past ten years has been most remarkable. In 1870 we were making somewhere about 20,000 tons, in 1873 about 160,000 tons, and to-day are turning out 1.750,000 tons; while the price has fallen below that of the finer brands of iron.

A few years ago—even those among us whose hair has hardly begun to turn gray can remember the time—no engineer except Telford, with his proposed cast-iron bridge of 600 feet span, had dared present plans of iron truss or arched bridges of 300 feet span; and Roebling was the only engineer bold enough to attempt much greater spans, even with suspension bridges.

To-day, with improved material and the better knowledge of their quality that comes of intelligent inspection and systematic test, we think little of trusses of 500 feet span, or suspension bridges of 1,000 feet and more; and it is even proposed to bridge the Forth at its expansion into the Frith with a steel truss bridge a mile long, containing two main spans of 1,700 feet each. Not the least remarkable and—to those who pay taxes in New York or Brooklyn to defray the cost of the "East River" bridge—interesting fact in connection with this scheme is that it is expected to cost but about $7,500,000. Who shall say that we are not making progress in this direction at least?

The reduction in cost of the purer, stronger, tougher and more homogeneous grades of so-called "steel" which are to take the place of iron in the near future, and of those which are made by the "open hearth process," especially, will depend principally upon the introduction of the regenerative type of furnace, the great invention of that greatest of metallurgical engineers, our colleague, Siemens, and of the lesser inventors who have followed his lead. With this furnace supplying a means of attaining any desired temperature with a pure mild flame and at a wonderfully low cost of production, we are able to produce the boiler steels and similar metals with an economy that permits competition in this field with even the product of the Bessemer process. With the closed furnace, the

attainable temperature is only limited by the temperature of fusion of the materials of the furnace. Could a new and sufficiently refractory furnace material be found, it might possibly be able to compete with the electric arc with which our colleague Farmer, that Nestor among our electricians, claims long ago to have produced the diamond. The melting of platinum in considerable quantities by Ricketts is now a familiar fact, and is an earnest of what may be expected in the more ordinary departments of metallurgy when such enormous temperatures shall be found manageable.

We are not yet absolutely free from annoyance by the presence of air-cells and minor defects in these "ingot-irons," as they are properly called; although such defects have ceased to be dangerous or in any way very serious. Captain Jones' method of compressing the solidifying ingot by steam pressure, and other devices in imitation of his, are giving us a very homogeneous metal.

Singularly enough, our people, enterprising as we are accustomed to consider ourselves, have not yet made use of the Whitworth system of compression of steel, notwithstanding the fact that its value has been known so many years, and though the wonderful strength, uniformity and toughness conferred by it have made "Whitworth compressed steel" famous throughout the world. Abroad, its use is extending, and guns, screw shafts and other heavy "uses" are often made of it. The venerable inventor informs me that he is preparing plans that will enable even large castings of peculiar shapes, as screw propellers, to be made of this material. Some dozen years ago, studying this method and its results, partly for my own satisfaction and partly to obtain material for a report to the Navy Department, I was greatly impressed with its efficiency as even then developed, and its work has since been wonderfully extended and its value correspondingly increased.

Our systems of inspection and tests of materials, of parts and of structures are steadily assuming satisfactory shape, and are becoming very generally, almost universally, adopted in all important work, whether public or private, and it will soon be the exception rather than the rule that supplies, material, or constructions of whatever kind, are purchased without a careful determination of their fitness for their intended purpose.

METHODS.

In my last address, I referred very briefly to the modern *Method of Manufacturing Machinery* in quantity for the market as dis-

tinguished from the old system, or lack of system, of making machines. This method compels the adaptation of special tools to the making of special parts of the machines and the appropriation of a certain portion of the establishment to the production of each of these pieces, while the assembling of the parts to make the complete machine takes place in a place set apart for that purpose. But this plan makes it necessary that every individual piece of any one kind shall fit every individual piece of another kind without expenditure of time and labor in adapting each to the other.

This requirement, in turn, makes it necessary that every piece, and every face and angle, and every hole and every pin in every piece, shall be made precisely of this standard size, without comparison with the part with which it is to be paired, and this last condition compels the construction of gauges giving the exact size to which the workman or the machine must bring each dimension.

Finally: In order that this same system which has introduced such wonderful economy into the gun manufacture, into sewing-machine construction, and into so many other branches of mechanical business, may become more general, and in order to secure that very important result, a universal standard for gauges and for general measurement, we need an acknowledged standard for our whole country—one that shall be an exact representation of the legal standard measure, and one which shall be known and acknowledged as such, and as exactly such.

It could hardly be expected that private enterprise would assume the expense and take the risk involved in this last work. Such work has heretofore only been done by governments. Yet among our colleagues are found the men who have had the intelligence, the courage and the determination to accept such risks and to meet such expense, and the men who have the knowledge and the skill needed in doing this great work. I think that the report of our committee on gauges and the paper of our colleague, Mr. Bond, will show that this great task has been accomplished, and we shall find that we are indebted to the Pratt & Whitney Co., to Prof. Rogers and to Mr. Bond for a system of measurement and a foundation system of gauges that will supply our tool makers and other builders with a thoroughly satisfactory basis for exact measurement and for accurate gauging.

It is encouraging to observe that this subject is attracting the attention of men of science, and that so distinguished a body as

the British Association for the Advancement of Science is taking action regarding it.

DESIGN.

Design is to-day conducted systematically and with scientific adaptation of means to ends. The day of the *soi-disant* inventor by profession has gone by, and the educated and trained designer has usurped his place. Reuleaux's kinematic synthesis determines the form to be taken by the machine when once the object sought in its construction is plainly defined, and an intelligent application of the laws and data of strength of materials gives its parts their safest and most economical forms and proportions.

The process of invention thus becomes a scientific one, and the inventor himself, instead of blindly groping for or guessing at results, is seen intelligently creating new and useful forms, and is now entitled to claim the higher credit and the nobler distinction that we gladly accord to him who performs so high an order of intellectual work, and to none more cheerfully than to him who applies the grand Science of Engineering to the production of new forms of mechanism.

As in the Fine Arts the great painter is known by his success in composition and in form rather than in color, so in our own art the best work is that which is distinguished by excellence of general design, of arrangement of detail and of proportion, while aimless ornamentation has no place. This characteristic of true art will become more fully illustrated as the scientific method of invention and design gains ground. The most direct and simple adaptation of means to ends will always be the object sought by the engineer; and the labors of one of our honorary members, Dr. Reuleaux, have led to the development of a scientific method of discovering those means.

HYDRAULICS.

Let us now look in another direction.

The mechanical engineer has open to him as his exclusive province one department which is, as yet, only partially developed in practice, although well advanced in theory. I refer to that of *Hydromechanics*, and especially the utilization of water power. Although one of the earliest opened by the old Greek engineers, it has been one of the latest developed. Archimedes, Ctesibius and Hero were familiar with the principles of fluid pressure; Torricelli, Pascal, Newton and Bernouilli developed the fundamental principles of

hydro-dynamics; Du Buat, D'Aubuisson, Prony, Eytelwin and, above all others, Darcy, supplied experimental data, but it has been reserved for our own generation to apply the knowledge so early acquired to the production of efficient hydraulic engines.

But a few years ago, the vertical water-wheel, as constructed by Fairbairn for moderate and for high falls, and the undershot wheel of Poncelet were the standard wheels in all countries, notwithstanding their cumbrous size, their slow movement and the great cost involved both in their own construction and in that of their machinery of transmission. Their efficiency was thought high, although rarely exceeding 75 per cent. These wheels have had their day, and nothing is likely to occur to save the whole class from ultimate disuse.

The turbine, introduced in an effective form by Fourneyon, a half century ago, and especially in the later forms of Fontaine, Henschel, Jonval, Schiele and others abroad, and by Boyden and his successors in the United States, has become the only water-motor in general use. This small, cheap, quick-running wheel has completely displaced all the older forms, whether overshot, undershot, or breast wheels.

The three principal types—parallel, inward flow and outward flow —are all in use and doing good work.

In Europe, they are all made by good builders, as here ; but the tendency seems to be, in the United States at least, to introduce most generally another and peculiarly American type—the inward and downward flow wheel, as illustrated in the wheel built by our fellow-member, Risdon.

In efficiency, notwithstanding the comparative neglect of these motors by scientific investigators, there has been a steady and important gain during late years. The improvements which have been *felt out* by makers, working often in the dark—for few builders claim to understand the principles of their art, and no two, even, ever agree in their statements of the principles underlying their practice—have resulted in a gradual elevation of standard, until to-day a wheel which, under favorable circumstances, cannot exhibit an efficiency of 80 per cent. must drop into the background. I have been asked to certify a trial giving, as claimed, 95 per cent. ; but that figure could, I am sure, only be attained by chance, if at all, when all conditions conspired in its favor. But wheels are, I have no doubt, doing work by the day and by the week at 80 per cent. It may be said that Boyden did as well a

generation ago. True, but only with large wheels, built as carefully as the chronometer is made, and fitted with polished buckets and diffusers, and tested under conditions purposely made the best possible. To-day our builders of turbines give their wheels such exact proportions and take such care in the ordinary work of the foundry that they obtain these high figures from wheels almost direct from the sand.

So far has this change gone that our theory of the turbine as modified by friction requires careful revision. Accepting the older co-efficients for friction and losses of energy, it will probably sometimes be made to appear, from experimental trials, that the wheels of our best makers are a trifle better than perfect. It would seem from figures sent me that friction, in a well-formed wheel, becomes partly a means of transfer of energy from water to wheel, and that the loss of efficiency due to that element is much less than has been supposed. In some of the later wheels, losses of energy due to eddies occurring within the flowing mass have been reduced to such an extent as to considerably improve their performance. In the regulation of the turbine, an excellence has been attained that is thoroughly satisfactory in some cases, and the best wheels have been found to give an efficiency at half and at three-quarters gate nearly equal to the best at full gate. As the efficiency at part gate is often more important than at full gate, it is easily seen that this means a vitally important gain.

MILLING.

A feature of recent progress of general interest, not only to engineers, but to every citizen, is the recent change in *Methods of Milling*.

It has been found that the cutting action of the millstone is not best adapted to the preparation of a good flour; but that the crushing action of the mortar and pestle or of rolls is much more efficient.

"Roller mills" have been long in use in Europe, and the Hungarian flour, so long noted as the finest in the world, owes its excellence, not simply to the gluten-charged wheat from which it is made, but largely to the systems of "high-milling" and of cylinder-milling, by which its fine grades are produced. The system of "high-milling" is a process of gradual crushing and grinding by a succession of operations, each of which gives a finer product than the preceding, while the intervals between them permit the grain to lose the slight heat produced by the slow-running stone. The

first step removes the silica coating, and the grain is next cracked, then broken up, and finally reduced to fine flour without loss of gluten or other injury, and with less waste than by the familiar system of "low-milling."

By the latest and best method, the grain is gradually reduced to fine flour by passing through a succession of pairs of rolls. In the great "*Walzen-Muhle*" at Pesth, from eighteen to twenty-four pairs are used in making the fine grades of flour. It is this method that is coming into use in our own country, and our hard North-western wheats are made by it into a fine, nutritious flour, rich in gluten, with its grain-cells intact, readily converted into the finest of bread, and capable of making 150 to 170 pounds of loaf per 100 pounds of flour. The great "Roller-Mill" at St. Paul, Minn., has a capacity of production of 500 barrels per day, and the hard wheat of the North-West supplies it with unexcelled grain.

TRANSPORTATION.

The modern system of collecting the grain raised in all parts of our country, from the Atlantic to the Pacific, from the Southern States to the great grain-raising districts of Dakota and Manitoba; the system of storage of the annual product, which now includes 1,600,000,000 bushels of Indian corn and nearly 700,000,000 bushels of wheat, in the great elevators of Chicago, Buffalo, New York and Boston; these latter methods of milling; our organization of a meat supply, taking herds of cattle from Texas for the markets of the North and East and for transportation to Europe; our system of packing meats at St. Louis, Cincinnati and Chicago, its carriage in refrigerator cars to the seaboard and in marine refrigerators to European ports; our methods of canning meats as well as vegetables, and thus preserving them from season to season; all these now familiar ways of reducing the cost of living are making further advancement toward a higher civilization easier and more rapid. They supply the first of the two essentials to healthful progress—cheap food and other necessarily consumed necessaries of life—and industrious habits of skilled labor are then to be relied upon in the production of the permanent forms of wealth.

Our systems of transportation are peculiarly the work of the engineer, and are the especial objects of his care. Planned by great engineers like John Stevens, John B. Jarvis, and others, of whom we boast as statesmen as well as engineers; built under the direction of Roberts, Welch, McAlpine, and other great constructors,

they remain in the hands of successors skilled in management and maintenance. All the enormous accumulation of capital in the form of rolling stock is the product of mechanical engineering, and the thousands of trains daily speeding across the land, each representing in value $30,000 to $150,000 and carrying hundreds of human beings, or property worth from $20,000 to $500,000, depend for their safety upon the thoroughness of the builders' work, and upon the coolness, skill and judgment of the man who handles throttle, brake and reversing lever—an obvious and forcible reminder of the importance of a profession, one of the humblest and least considered member of which is laden with such enormous responsibility.

ELECTRICITY.

Turning now to the work of the last-established branch of our profession, *Electrical Engineering*, we find ourselves still in the midst of a revolution, the progress of which we are all watching with unusual interest—the displacement of our older methods of supplying light and power by a new system, which but lately was but the toy of science, and which comes out of the least utilitarian of all the branches of pure physics. Brush has set up his blazing, sun-like, arc-lights in nearly every large city in the world; Edison has spread a net-work of conductors throughout the most densely settled part of New York City, distributing many thousands of his clear mellow lights to send their soft, white rays into corners never yet revealed by the feebler yellow light which they displace. It remains to be learned what is to be the cost of the new method of illumination; no figures that I consider wholly reliable have yet been given. It seems sufficiently certain, however, that the arc light is much more economical than gas—the same quantity of light being demanded—for the illumination of streets, public squares and large interiors, while interior illumination by the incandescent lamps is still generally more costly than any other usual method.

The danger to life and property which come in with the new light are becoming rapidly less, as safe methods of laying and connecting the "mains," of handling the plant and especially more careful and skillful inspection become generally known and practiced. They still remain so great as somewhat to retard the introduction of the electric light.

The secondary batteries of Faure, Planté, and others are likely to aid, after a time, in bringing the light into use in many localities

in which it would otherwise be impossible to adopt it with satisfactory results and in cheapening the cost of supply. They are still too cumbersome to be of as great value for general purposes as was hoped when they were first invented.

Despite every difficulty and every objection, however, the electric light is steadily and surely coming into a very wide field of application. Its beautiful whiteness, its brilliancy and clearness, its richness in the actinic rays, and therefore its power of revealing every shade of every color, and of producing the chemical changes of photography, its freedom from heat, from vapor and from gaseous poisonous products of combustion, and even its curiously interesting effect in promoting the growth of plants, must all prove qualities of such importance that its extensive introduction, although hardly its exclusive use, must be soon accomplished. As remarked recently by Siemens, gas will long remain the poor man's friend, supplying his rooms with light, and probably his kitchen, ere long, with heat.

Little has yet been done in the electrical transmission of power, except to determine experimentally the efficiency of the system.

I stated last year that the efficiency of the Edison system had been determined, and found to be about 90 per cent. Howell's results have been confirmed by Hopkinson, and by Siemens abroad, and are also checked by reference to Tresca's earlier work. Recently the Messrs. Gibbs have made an extended study and test of the Weston machine; and they also find the earlier reported figures for electrical transmissions more than confirmed. Taking the probable efficiency of the two machines forming the system in electrical transmission at 85 per cent. each, we obtain a net efficiency of the system, exclusive of conductor, of above 70 per cent.—this is precisely Tresca's figure, if I remember aright—and, allowing liberally for losses on the line, we may say that 60 per cent. of the power generated may be utilized. But a good engine of large size should give a horse-power with 2 to $2\frac{1}{2}$ pounds of coal per hour, while the small engines which may be displaced by it will demand from 8 to 12 pounds, thus giving an enormous advantage to a system distributing a large aggregate of power to many small users. We shall all look with great interest to the result of actual trial. The electrical railways at Berlin, in Paris, and in Ireland, and Edison's road at Menlo Park, are not likely to remain long uncopied. Our own elevated railroad system offers the best possible field for the utilization of this system; and the often-proposed

scheme of burning all our fuel at the mine, and transmitting light, heat, and power in our cities along electrical conductors, begins to seem almost a practical one. We may begin to look once more to thermo-electrical generation as a possible method of transformation at the source of power, as proposed by our distinguished colleague, Farmer, years ago. The fact that while a 4-horse power dynamo deposits about 700 pounds of copper in 24 hours, expending, say, 400 pounds of fuel, at least, in usual work, Farmer deposited 400 pounds of copper 20 years ago, nearly, with an expenditure of but 109 pounds of coal burned in his thermo-electric battery, is an important one to be kept in mind in this connection. We may, perhaps, look soon to see this branch of the subject again taken up, and a battery again constructed capable of melting tungsten, and of fusing 8 pounds of platinum in 20 minutes.

Before leaving this subject, it is pleasing to note that in the introduction of new electrical units, our great predecessor, James Watt, is accorded deserved honor, beside Ampère, Weber, Ohm, Coulomb, Volta and Faraday, and that so barbarous a system of nomenclature is made a means of perpetuating the name of so great an engineer, as well as those of such great physicists.

STEAM.

In *Steam-Engine Practice* we are not now advancing rapidly. The introduction of the "drop-cut-off" in 1841, by Sickles; of the now standard type of automatic valve gear in 1849, by Corliss; of the high-speed engine, twelve years later, by Allen and Porter; of the combined advantages of jacketing, superheating and reheating, and the definite acceptance of the compound engine in later years, still constitute the complete history of modern steam engineering; but we are, nevertheless, continually gaining a knowledge of the best methods of handling higher steam; of attaining higher piston speed; of securing greater immunity from cylinder condensation and leakage, and of providing against other causes of waste. We are just beginning to perceive what principles must govern us in the endeavor to secure maximum commercial efficiency, and how economy in that direction is affected by the behavior of steam in the cylinder, and by the mutual relations of all the various expenditures that accompany the use of steam power.

The younger Perkins are still leading in the practice of carrying high steam, and make 400 pounds per square inch—27 atmospheres—as a usual figure while they are experimentally repeating the work

of the elder Perkins, and of Dr. Albans, of forty years ago, working steam at 1,000 pounds or nearly 70 atmospheres.

Unfortunately, the gain to be anticipated by the use of these enormously increased pressures does not seem likely to be very great, unless some decidedly less wasteful kind of engine can be devised in which to work it. The "Anthracite," with steam at 300 pounds and upward, was less economical in fuel than the Leila, carrying about one-third that pressure. Emery has stated that a limit seems to be found at about 100 pounds to economical increase of pressure; and Stevens finds a limit due to the causes producing or modifying the geometrical character of the indicator diagram, inside of 250.

One of the most interesting and curious, as well as important, deductions from the rational theory of engine efficiency is the existence of an "absolute limit to economical expansion,"—lying far within the previously accepted limit—due to the fact of increase of cylinder condensation and waste with increase in the ratio of expansion, which places an early limit to the gain due to expansion *per se*. It seems possible, if not certain, that this point is often actually reached in ordinary engines within the range of customary practice.

All these facts combined point to a probability that we have little to hope for in the direction of increased steam-engine economy with our standard machinery. Change in the directions that I have already so often indicated are evidently to be our sole reliance—changes limiting loss by cylinder condensation. Probably the surrounding of the working fluid by non-transferring surfaces is our only resource, in addition to, or in substitution for, the now well-understood expedients of high piston speed and super-heating. Until that is done, steam jacketing remains a necessary and unsatisfactory method of reducing losses. With a non-conducting cylinder, were it procurable, we might secure very nearly the efficiency of the ideal engine, friction aside, as it would be a "perfect engine," and no natural limit would then exist to increasing economy. Were this accomplished, we might at once reduce the cost of steam power by about one-half in our best engines, and to probably one-fourth or one-fifth the present cost in ordinary machines.

In steam engineering, both physicists and engineers are more than ever attracted to the study of those phenomena which produce the familiar and enormous differences, even in the best practice, between the thermo-dynamic and the actual efficiencies of engines. The subject lies in that "march-land" territory between science and practice, which few of the profession can explore from both sides,

and it has remained less known than it would otherwise be were it either a matter of purely physical science or of practical experience. Fortunately, we are likely soon to see it thoroughly studied. The debate which arose not long since between Zeuner, the distinguished physicist, as a representative of pure science, and Hirn, the no less distinguished engineer, as an experienced practitioner and skillful experimentalist, in which the differences, to which I have so often called attention, of fifty per cent. or more between the "theoretical" efficiency and the actual performance of the best steam engines seem for the first time to have been given prominence in Europe, has led to a much closer study of the matter than could possibly otherwise have been brought about.

On this side the Atlantic, the discussion of steam engineering efficiencies has been carried on earnestly, if not always with that knowledge that should precede criticism, and it is to be hoped and anticipated that the engineer may ere long be put in possession of positive facts and real knowledge that may aid him in so designing and so applying this greatest of modern inventions as to attain the maximum of economy.

Ten years ago, nearly, I took occasion to state in a report to the President of the United States on the exhibited machinery of the Vienna exhibition of 1873, printed later with the other reports of the United States Scientific Commission, that, "The changes of design recently observed in marine engines, and less strikingly in stationary steam engines, have been compelled by purely mechanical and practical considerations. The increase noted in economy of expenditure of steam and fuel is, as has been stated, due to increased steam-pressure, greater expansion, and higher piston-speeds, with improved methods of construction and finer workmanship. These several directions of change occur simultaneously, and are all requisite. To secure maximum economy for any given steam-pressure, it is necessary to adopt a certain degree of expansion which gives maximum economy for that pressure under the existing conditions.

"This point of cut-off for maximum efficiency lies nearer the beginning of the stroke as steam-pressure rises. For low pressure a much greater expansion is allowable in condensing than in non-condensing engines; but, as pressure rises, this difference gradually lessens. For example, with steam at 25 pounds by gauge, the best economical results are obtained when expanding about three times in good condensing engines and about one and a half times in non-condensing engines. With steam at 50 pounds, these figures be-

come five and two and a half, respectively; and at 75 pounds, the highest efficiency is secured in condensing engines, cutting off at one-fifth, and in non-condensing engines, with cut-off at one-third stroke.

"Owing to the decreasing proportional losses due to back-pressure and to retarding influences, the departure from the economical result indicated for the perfect engine becomes greater and greater, until, at a pressure between 200 and 250 pounds, the proper point of cut-off becomes about one-sixth or one-seventh, and very nearly the same for both classes of engines, and the increase of efficiency by increase of pressure and greater expansion becomes so slight as to indicate that it is very doubtful whether progress in the direction of higher pressure will be carried beyond this limit."

These conclusions were derived from careful observation of the performance of unjacketed "single cylinder" engines and a comparison of the ratios of expansion of those exhibiting greatest economy. It is interesting to note that later, and probably more reliable methods of comparison than were then familiar go far in confirmation of the opinion then expressed. I think that I have been able to prove the existence, as just stated, of an "absolute limit of economical expansion," which, whatever the ratio of steam pressure to back pressure, in all known heat engines probably falls within the range of familiar practice. Advance beyond the best efficiency of to-day in ordinary engines seems likely to be very slow and not at all likely ever to be very great.

Extended experiments will be needed to secure all the facts demanded by the designing engineer, and to furnish constants for the approximate theory of efficiency, which is only, as yet, his sole guide. An exact theory is one of those things for which he hopes but which he does not expect soon to see. Some experiments have already been made, but they contribute only the first step. Those made by order of the Navy Department, and principally by Isherwood, and those of Hirn have hitherto been our sole guide, but a new line of more direct investigation of the laws governing internal, or cylinder, condensation has been inaugurated by Escher, of Zurich, and we are able to see a fair prospect of obtaining definite information in this direction.

Escher finds, in the case taken by him, that this waste varies nearly as the square root of the period of revolution and of the pressure, and is nearly independent of the back pressure—conclusions which are especially interesting to me as corroborating assumptions, based

on general observation and non-experimental practice, made by me previously in developing an empirical system of design.

In steam-boiler engineering, the only observable change seems to be the slow but steady gain made in the introduction of water-tube coil boilers and sectional boilers, and in the extension of a rational system of inspection and test while in operation. To-day, the intelligent owner of boilers secures inspection and test, with insurance, by intelligent engineers and responsible underwriters, as invariably as he obtains inspection and insurance of his buildings. Under this system, steam-boiler design, construction and management is becoming a distinct art, based upon real knowledge. The system of forced circulation proposed by Trowbridge, and perhaps others, seems to me likely to prove useful in the solution of the problem to-day presented.

MARINE ENGINEERING.

In *Naval Architecture and Marine Engineering*, the fruits of the labors of our colleagues are seen in the constantly growing magnitude of our steamships, and in the steadily increasing celerity and safety which mark their unceasing transit from continent to continent.

The "Alaska" makes trip after trip, as regularly as a ferry boat, in all but the most trying weather, from Sandy Hook to Queenstown in a week, and has made 18 knots an hour for 24 hours together, and the "Arizona" and the "Servia" are closely rivaling this wonderful performance.

A half dozen years ago I was consulted by an enterprising steamship proprietor who desired to learn how far the substitution of steel for iron would aid in the attainment of his aim—the construction of a line of steamers to make 25 miles an hour from shore to shore. A similar project has been lately discussed, and it would not be surprising to the well-informed engineer if the plan is carried out within this decade.

Even the ill-famed line between Dover and Calais and other channel routes are benefiting at last by the achievements of the mechanical engineer, and the "Invicta," a steamer considerably smaller than the "Pilgrim," has crossed the channel in fair weather in a little over one hour running time—a speed of 18 knots, or 21 miles, an hour—and the "twin" steamer "Calais-Douvres" makes the passage in an hour and a half so steadily that the trying scene

so unpleasantly remembered by every unfortunate who has crossed on the old boats, no longer occur.

The most attractive and difficult of problems presented to the engineer—*to secure a maximum speed, combined with good cabin accommodations and paying cargo capacity*—demands an extent of knowledge and experience, an ingenuity, and a degree of practical skill which are demanded by no other task set before the engineer.

My attention has been called to this subject more strongly than ever before by experiences arising recently in my own practice, and I have been interested in observing how largely the problem resolves itself into one of boiler concentration. The engineering of the machinery is a minor matter; to get a maximum of steam production from a minimum space and weight in the boiler-room and coal-bunker compartment, is a vitally important matter. Even when the cargo space is surrendered, it is difficult to secure speed and good cabins in small steamers, and the scheming of a high-speed yacht of ample accommodations and of good sea-going qualities is a most perplexing piece of work.

Not the least remarkable work in this department has been done, however, on very small craft. Torpedo-boats require but little weight-carrying displacement, and can be loaded with machinery, and thus the disadvantage of their small size is, partly at least, compensated. They have been given astonishing speeds, but only by forcing boilers tremendously to drive the lightest of engines in the lightest possible hulls, over, rather than through, the water.

The art of getting high speed is extremely simple in principles but very difficult in practice. It embraces a very few essential requirements:—(1) Lightness of hull; (2) Excellence of form; (3) Minimum weights carried, whether in cargo, accommodations, fuel, or machinery; (4) Great impelling power, *i. e.*, for best work, a steel hull; small cargo; few stores; fuel for the least time permitted by ordinary prudence; contracted cabins; small engines driven at the highest attainable speed of piston and by maximum safe steam-pressure, and finally, and perhaps principally, boilers of small size, carrying high steam, with minimum water space and forced to the very limit of their power. The art of getting large grate area into a contracted and peculiarly shaped cross-section of hull is one still to be learned.

The torpedo-boats of Thorneycroft and Yarrow in England, and of Herreshoff in the United States, illustrate the most successful practice of to-day, and their attainment of speeds exceeding twenty

miles an hour may be accepted as the most remarkable triumphs of recent mechanical engineering.

With light hulls, weighing but about one-third their displacement, having such fine lines as to occupy but six-tenths the circumscribing cylinder, burning 100 to 150 pounds of fuel on the square foot of grate, carrying 120 pounds of steam, their little engines making 800 to 900 feet of piston speed per minute, at from 500 to 700 revolutions, and weighing but 50 or 60 pounds to the horse-power, this kind of work is locomotive practice of the most radical sort. The secret of success here lies largely in ability to drive the boilers, which are of the locomotive type, forced by powerful fan "blowers," and give a horse-power to each $1\frac{1}{2}$ or 2 square feet of heating surface, and from 20 to 30 horse-power to the square foot of grate.

Now that we are using surface condensation exclusively, there is comparatively little difficulty in the introduction of locomotive practice at sea.

But remarkable and important as is this phase of steam engineering, these little craft have revealed in their performance facts of equal importance in another department. The speeds attained are high, even for large ocean steamers; they are enormously high for such small vessels. It is found that, passing the speeds of 10 or 12 knots, which correspond to high speeds in larger craft, the rate of variation of resistance passes a maximum, and then falls from variation as the cube of the speed, or higher, to the $\frac{2}{3}$ power, and becomes, finally, directly proportional to the speed at their highest velocity, thus giving a comparatively economical performance.

Should the same change of law occur with large steamers, maximum railroad speeds at sea may yet prove to be attainable, when—as I have no question will, ere many years, be the case—we shall burn at sea a hundred and fifty pounds on the square foot of grate in locomotive or sectional boilers, with steam at 200 or 300 pounds pressure, driving engines at 1,000 or 1,500 feet piston-speed per minute, turning screws fitted with guide blades as already practiced abroad, and with machinery of steel in steel hulls of less proportional weight than these torpedo-boats.

It is by such changes as these that the mechanical engineer and his colleagues in the trades are gradually revolutionizing the art of war. Before many years, we hope, war will be made so destructive that no nation will dare venture into a naval contest, and the en-

gineer will have then entitled himself to the glorious distinction of being victor over victory itself. He may thus bring about the death of all war, and may give new meaning to Schiller's song:

> "Honor 's won by gun and saber;
> Honor 's justly due to kings;
> But the dignity of labor
> Still the greatest honor brings."

The screw has become the only instrument of propulsion where it can be used, and I can see no reason to suppose that it will not so remain indefinitely; but engineers, who have hitherto been blindly groping to find some new and peculiar form which may possess mysterious principles of efficiency, have now become fully cognizant of the analogy between the screw propeller and the turbine, and are seeking to apply the well-developed theory of the latter to the former.

The value of a system of guide blades and of methods of direction of the currents approaching and leaving the screw, is being determined experimentally, and it is to be hoped that, before long, we may see this instrument rival the better classes of turbine and exhibit an efficiency of 80 per cent. and upward. Thorneycroft has already done good work in this direction.

AËRONAUTICS.

It is the reduction of weight of hull and machinery, so remarkably exemplified in recent naval engineering, and the no less remarkable recent improvement in performances, that renders it more than possible that we may be on the eve of real advancement in *Aëronautics*.

In my last address, I referred to the work done up to that date, and endeavored to show how far the researches of Marey, of Pettigrew, of De Lacy and Houghton, had developed the experimental science of aëronautics, and how far the efforts of Dupuy de Lôme had supplemented the labors of the brothers Montgolfier, of Charles, of Greene, of Flammarion, and of Glaisher in actual navigation of the air. I took occasion to indicate what seemed to me to be the promise of the early future and the indications of ultimate success.

Since then, little or nothing has been done, either in research or in aëronautic practice; but Pole has made a study of the problem,

and from known data has determined what we may probably expect to see accomplished, when, as may soon occur, the modern methods of locomotive and marine engineering shall be applied to aërial steam navigation by means of balloons. He studies the problem as outlined by Lavoisier a century ago, 1783, as attacked by Giffard a generation ago, in 1850, and as so nearly solved by him and by Dupuy de Lôme during the Franco-German war. Both attained speeds of between 6 and 7 miles an hour in "*dirigeable*" balloons.

Calculating, from known data, the necessary size of balloons to carry the demanded weights, obtaining by direct reference to known performance the probable resistance of the air-ship, taking the possible least weight of motor at 40 pounds per horse-power, net, 50 pounds gross and 75 pounds including the condenser, and allowing for nearly 20 tons of cargo, Pole finds that a balloon, of spindle form, 100 feet in diameter and 370 feet long, may be driven by this torpedo-boat style of machinery at the rate of about 30 miles an hour. An air-ship of one-half these dimensions would steam 20 miles, and one built on one-third scale 12 miles an hour.

These are certainly interesting and remarkable figures; but, as their author remarks, they come fairly and legitimately from existing data. Should the time ever come when the practical difficulties of construction can be fully overcome, it is evident that success in aërial navigation will promptly follow, and we may hope that the time is not far distant when this new product of modern mechanical engineering may become practically useful to the world.

To-day, however, man, with all his vaunted intelligence and with all his wonderful powers, is in this field beaten by every bird that flies, and even by so minute an insect as the gnat, which is only to be seen when disporting in the sunbeams.

Elmerus and Joseph Degnan have, as yet, no followers known to fame, and stand beside Bushnell and Fulton, who inaugurated submarine navigation, but are yet without successors.

CAPITAL AND LABOR.

In singular and discreditable contrast with all this gain in recent and current practice in engineering stands one feature of our work which has more importance to us and to the world, and which has a more direct and controlling influence upon the material prosperity and the happiness of the nation than any modern invention or than

any discovery in science. I refer to the *Relations of the Employers to the Working Classes* and to the mutual interests of labor and capital. It is from us, if from any body of men, that the world should expect a complete and thorough satisfactory practical solution of the so-called "labor problem." More is expected of us than even of our legislators. And how little has been accomplished?

Yet it would seem that the principles involved are simple and that the practical difficulties *should* be readily overcome. The right of every man to buy or sell labor wherever or whenever he may choose, and wherever and whenever he can make the best bargain, is one of those rights which are natural and inalienable. The right of every man to engage in any occupation, or to enter into any department of honest industry, to train his children for any productive occupation or to secure for them any kind of employment, is an equally natural and inalienable right. The privilege of accumulating property to any extent and by any honorable and legitimate means, is also naturally and legally accorded to every citizen. It would seem obvious that one of the first claims of the citizen upon the State is that he shall be absolutely assured of these as constitutional rights. Any infraction of such rights and any attempted contravention of such privileges, whether by individuals, by legally constituted corporations, or by associations unknown to the law, should be promptly dealt with, and so severely, whether the culprit be of high or low degree, that the offense shall not be likely to be repeated.

No legislation should be permitted that shall injuriously affect any morally unobjectionable industrial enterprise or that shall impede any fair commercial operation, whether in the exchange of commodities or the transfer and use of capital. Only such a tariff system, even, can be safely permitted as shall encourage fairly the growth of such new industries as are adapted to our climate, soil and other natural conditions.

The prosperity of a people is dependent upon their industry, integrity skill, and enterprise, as well as upon the natural resources of the country, and the object of every government and of all legislation is to protect the people in their right to a fair reward for their industry, skill and enterprise, to promote that mutual confidence that comes of real business trustworthiness, and to develop the natural resources and advantages of the State. The protection of the individual in his right to learn, to labor and to traffic; the encouragement of national enterprises, the diversification of indus-

tries, the promotion of the ability of the people to produce valuable materials and all kinds of products of the higher classes of skilled industry, the encouragement of invention and the making of the nation independent of all possible rivals or enemies in the production of whatever is necessary to the existence or the comfort of the people, are all perfectly proper objects of legislation. No legislation which neglects or opposes these objects can aid us. No legislation can serve the nation which aims to help either the employer or the employé, either the capitalist or the laborer, *alone*. No industry can permanently succeed which does not make both classes prosperous, and no state-craft is deserving the name which does not aim at the support of both. If either is discouraged and driven out of the field, business ceases and suffering results.

Again, force and intimidation have no place in matters of business. All legitimate operations, whether in commerce or manufactures, are the result of mutual agreement for mutual advantage. Strikes and lockouts, as well as their usual but shameful concomitants, intimidation and violence, are wholly out of place in our industrial system and should be repressed by every legal means, as absolutely opposed to the spirit of civilization and to the letter of our Declaration of Independence. The simplest principles of political economy and social ethics cover this matter fully. Labor, like any other salable possession, will have a value determined accurately by the great law of supply and demand, and the interruption of traffic in labor, and at the same time the compulsory interruption of production, in the end only result in serious injury to both parties to the controversy and to the whole country as well.

The introduction of a general system of arbitrament, the formation of unions between associated employers and associated employés, the diversion of the trades unions into their legitimate channels of usefulness, will ultimately, we may be sure, effectually reform all the existing abuses in this direction. Already workingmen are learning that strikes almost invariably cost far more than they gain; capitalists are beginning to understand that their pecuniary interest, as well as ordinary humanity, dictate careful consideration of, and respect for, the rights and interests of labor, and, ere long, when employers sustain labor exchanges in all our great cities, and when trades unions confine themselves to benevolent enterprises and the assistance of those members who desire to reach better paying fields of labor, we may expect to see every industry

settle down to a steady, unintermitted routine which will give maximum production, while every worker will have uninterrupted employment at rates of pay which will be the maximum value of the labor sold. If every boy were made familiar with Nordhoff and every man with Adam Smith and Spencer and J. Stuart Mill, we might hope that it would become universally understood that highest prosperity can only come when business can proceed without interruption by strikes, lockouts, or unintelligent legislation. A perusal of Eaton's excellent report on Civil Service suggests the thought that such a system is as desirable in every industrial organization as it is in the public service.

Grimm, in his life of Michael Angelo, says that three powers rule every state, and they are variously classed as "Money, Mind, Authority," as "Citizenship, Science, Nobility," or "Energy, Genius, Birth." I would say, in each individual, "Talent, Power and Character," or "Genius, Strength, Integrity," are ruling powers, but that we are yet to see them rule the State. That the time is coming we may, I am sure, both hope and believe, but a great change must first take place.

We need a Junius to write, a Burke to speak, and a Chatham to illustrate a real reform.

The elements of social economy are yet to become known to our people; the most obvious principles of statesmanship are yet to be learned by our legislators, and we have still to look forward to a time when our men of business and our working people shall be fairly and respectfully considered by those who direct public policy. Before the needed reform can be made productive of general good we must return to the original theory of our government—that all government has for its object simply the preservation of the rights of the people in their pursuit of the best life, the highest liberty and the purest happiness; that it should guarantee to all, of whatever race, creed, powers or sex, a common right to live, to learn, to labor and to acquire and hold property, with absolute freedom of thought, speech, and right-doing.

To attain all that we desire and to secure highest efficiency in our political and social system, we must have a business man's and a working-man's government. The professional politician and the machine system must become extinct. Our public policy and our law-making must be made subservient to industrial interests. The people, and not self-seeking ward politicians, must frame the code and direct the expenditure of public funds.

SYSTEMATIC PROMOTION OF INDUSTRIES.

And these considerations bring up the question:—How can so desirable a change in politics and in industry be brought about?

There is but one answer: By systematic and carefully planned encouragement of all industries, a system that shall illustrate those methods which are the true object of all government, a system, also, which shall supply means by which full advantage may be taken of all those opportunities, which present themselves to every citizen of the United States.

Such bodies as this must aid our legislative assemblies in developing a *Scheme of Industrial Organization*, that shall exhibit highest possible efficiency—one that will prepare the children and youth of the country to enter upon lives of maximum usefulness, and to do the work that may be given them to do with ease and comfort, while, at the same time aiding them to attain health, happiness and content, even if not independence and wealth.

It is easy to see what must be the leading features of such a system. Since the prosperity of the State and of the people depends upon the integrity, the skill and the industry of its citizens, it is evident that the cultivation of good morals, a keen sense of right and a high sense of honor are primary requisites; that the instruction and training of every youth in the art for which he is best fitted is essential; that a fair general education is equally necessary to afford sources of intellectual pleasure; that a reduction of the hours of labor to a minimum healthful length must give opportunity for continual self-improvement and for healthful recreation.

It is obvious that we must find ways of encouragement of those industries the success of which are best assured by our climate, our soil, our topography, and by our social and political conditions. We must take steps to secure by systematic legislation and by every other proper means a diversification of skilled industries and such a relative distribution of agricultural and manufacturing population as shall bring to each all the necessaries and comforts of life at minimum cost.

It is our task to study the soils, climates and natural resources of this wide land of ours, to learn what products of the soil and what manufactured articles can be made to give the best return for time and money invested, and then to systematically develop by public policy and private enterprise, every such industry, securing the highest skill, the most reliable labor and the finest artistic talent

by conscientiously cultivating them. Skilled labor has a steadier market and makes a steadier market than unskilled, and our effort should evidently be to lead the world in its development, cultivating all profitable manufactures which demand greatest skill and highest talent; encouraging a varied industry; making the expenditure of capital and labor on transportation and on coarse work a minimum, and making the most of every pound of raw material brought into our market before putting it on sale again. Any system of encouragement of domestic industries that may be adopted must evidently include a practical and fruitful plan of careful education and of regular training in the trades and arts capable of successful growth among us, making our people the equals, and, if possible, the superiors, of their competitors in other countries, in intelligence, skill, knowledge and enterprise. It must introduce new industries and diversify old ones. It must teach the child, train the youth, and protect the man from excessive outside rivalry.

Only when our whole population has become as intelligent, as skillful, and as well informed in every branch of every industry, existing or arising in the State, as any other people can possibly be, only then, may we rely safely upon profiting fully by all those advantages due to our natural position and resources.

Such a plan must be carefully considered by the sages of the community, and only adopted after deliberate study and thoughtful consideration. But a few general principles are readily discoverable. A half dozen years ago, at the request of a commission appointed by the State of New Jersey, of which commission I had the honor to be appointed secretary, I prepared a general outline of such a scheme as that which now interests us, and based it upon the following "platform":

Such a plan, to be satisfactorily complete, must comprehend—

A common-school system of general education, which shall give all young children tuition in the three studies which are the foundation of all education, and which shall be administered under compulsory law, as now generally adopted by the best educated nations and States on both sides the Atlantic.

A system of special adaptation of this primary instruction to the needs of children who are to become skilled artisans, or who are to become unskilled laborers, in departments which offer opportunities for their advancement, when their intelligence and skill prove their fitness for such promotion, to the position of skilled artisans. Such a system would lead to the adoption of reading, writing, and spell-

ing books, in which the terms peculiar to the trades, the methods of operation and the technics of the industrial arts should be given prominence, to the exclusion, if necessary, of words, phrases and reading matter of less essential importance to them.

A system of trade schools, in which general and special instruction should be given to pupils preparing to enter the several leading industries, and in which the principles underlying each industry, as well as the actual and essential manipulations, should be illustrated and taught by practical exercises until the pupil is given a good knowledge of them and more skill in conducting them. This series should include schools of carpentry, stonecutting, blacksmithing, machine work, etc., etc., weaving schools, schools of bleaching and dyeing, schools of agriculture, etc., etc.

At least one polytechnic school in every State in the Union, in which the sciences should be taught and their application in the arts indicated and illustrated by laboratory work. In this school, the aim should be to give a certain number of students a thoroughly scientific education and training, preparing them to make use of all new discoveries and inventions in science and art, and thus to keep themselves in the front rank.

A system of direct encouragement of existing established industries by every legal and proper means, as by the encouragement of improvement in our system of transportation, the relief of important undeveloped industries from State and municipal taxes, and even, in exceptional cases, by subsidy. It is evident that such methods of encouragement must be adopted very circumspectly and with exceedingly great caution, lest serious abuses arise.

This system should comprehend, perhaps, a Bureau of Statistics, authorized, under the law creating it, to collect statistics and information relating to all departments of industry established, or capable of being established, in the State.

I would place at the head of this whole system of aid and encouragement of all legitimate industries a great central University of the Useful Arts and Sciences which should be the directing member of the whole organization, furnishing higher instruction to the son of every citizen who can find his way to it, supplying the polytechnic schools and colleges with the most learned and talented instructors, aiding by scientific investigations the development of every industry, and serving as an attractive nucleus around which should gather the great men of every department to serve the State in that highest of employments, the instruction and training of our

youth, and by giving counsel to legislators and executive officers of every department of the Government, in concert with our already established National Academy of Sciences.

Washington urged the creation of a National University, a primary object of which should be the education of youth in the Science of Government. Jefferson, also, urged the foundation of "a National Establishment for Education," and John Stuart Mill has said: "National institutions should place all things that are connected with themselves before the mind of the citizen in the light in which it is for his good that he should regard them."

Experience at home and abroad shows that systematically conducted schools of art, and trade schools, are vastly more efficient and economical in the education and training of youth than the best-managed mill or workshop. Every operation can there be taught, and the learner made perfectly familiar with each detail, without causing the inconvenience and pecuniary loss which are sure to come with such an attempt in the shop.

Very much such a complete system of technical science of instruction and of industrial education has been incorporated into the continental educational structure, and there places before every child in the land the opportunity of giving such time as the social position and pecuniary circumstances of its parents enable them to allow it to devote to the study of just those branches which are to it of most vital importance, and to acquire a systematic knowledge of the pursuit which surrounding conditions or its own predilections may lead it to follow through life, and to attain as thorough a knowledge and as high a degree of skill as that time, most efficiently disposed, can possibly be made to give him. There is here no waste of the few months, or years, of to him most precious time, which the son or the daughter of the humblest artisan can spare for the acquisition of a limited education. Every moment is made to yield the most that can be made by its disposition in the most thoughtfully devised way that the most accomplished artisans and the most learned scholars, mutually advising each other, can suggest. One day in such schools as those here described is of more value to the youthful worker than a week in the older schools, or than a month in the workshop or the mill. Thus, while the fact is recognized that a general and a liberal education is desirable for every citizen, the no less undeniable fact is also recognized that few citizens can give the time to, or afford the expense of, a symmetrical general course, and that the interests of the individual and of the State

unite in dictating the provision of such systems and means of industrial education and training.

It is in consequence of the adoption of an intelligent and extensive system of the character of that which I would propose for our own country, that it has become now generally admitted that Germany is the best educated nation of the civilized world. (There is danger that the United States may, with reason, be reckoned the worst.) Germany is gaining a better industrial position daily; our own country is retrograding in all that tends to give manufacturing pre-eminence, except in the ingenuity, skill and enterprise of its people; and the one great, the vital, need of our people is a complete, efficient, and directly applicable system of technical instruction and of industrial training, if they are to avoid the successful and impoverishing competition of nations which have already been given that advantage by their statesmen and educators a generation earlier. The question whether this comparison shall remain as startling and as discreditable to the people of the United States in future years as it is to-day, is to be settled by the ability of our people to understand and appreciate the importance of this subject, by the interest which the more intelligent classes may take in the matter, and upon the amount of influence which thinking citizens and educated men, and the real statesmen among our legislators may have upon the policy and the action of the General and the State Governments. The promptness and energy which we may display in an effort to place ourselves in a creditable position among educated nations, will be the truest gauge of the character of the people of the United States. Judged by her progress in this direction, Europe is far in advance of us in the most essential elements of modern civilization. There, instead of standing aloof from each other, and instead of forgetting, as is too frequently the case in our own country, those great facts and those imperative duties which every statesman does, and which every citizen should, recognize, the governing and the educated classes have worked together for the common good, and have given Germany, especially, a vantage-ground in the universal struggle for existence and wealth which is likely, in the future, to enable that country for many years steadily to gain upon all competitors.

Our own work, thus far, has been desultory, sometimes ill-directed, and rarely thorough or systematic. Our "technical-schools," so-called, are often modified trade schools, and our few trade schools frequently aspire to the position of polytechnic schools, and both

classes are confounded in the minds of very many, even in the profession, and their work is seldom done with that maximum efficiency which can only come of intelligent organization and definite aims and fields of work. So it happens that while the system of general primary education is more widely spread and more effective than in any country in the world, and while we have a larger number of schools, in proportion to population, than perhaps any other country, we are nearly destitute of trade schools, and have extremely inadequate provisions for industrial education of any kind and for any class of our people.

This system of preparation of every citizen for useful work and a prosperous life being adopted, there remains to be considered what can be done to aid the great industries into the channels of which all this skill and training in the arts and applied sciences is to be directed.

GENERAL CONCLUSIONS.

A complete working system of preparation being inaugurated, all is done that can be done for the individual in the endeavor to place him on a fair vantage ground in the struggle for survival which is going on throughout the world. Beyond this he must trust principally to his own intelligence, skill, industry and frugality for success in the effort to secure the necessaries and comforts of life, and to acquire luxuries, a comfortable independence in old age, and the means of starting his children on a higher level than that which he has himself reached.

A plan for the encouragement of our industries and to secure permanent prosperity must include a general policy of legislation which shall aid the capitalist to safely invest his funds in manufacturing enterprises, or in agriculture; shall assist the workingman and the workingwoman to find remunerative and permanent employment, shall protect every one in the right to sell his capital or his labor at the best market value, wherever and whenever he chooses to offer it, and to give and to take in fair bargains without let or hinderance.

Such a policy must sustain every good workman in the effort to secure a good price for his labor, and every employer against every attempt to compel him to pay good wages for bad work or to surrender the control of his business or his property to any other man.

Legislation must be general, and must, so far as possible, avoid either direct or indirect interference with the natural currents of

trade. It must facilitate, not obstruct, natural industrial movements. The welfare of the people, and not of any class, rich or poor, must be studied.

The fruit of such a system as I have outlined will be fully seen only when all our labor is skilled and intelligent; when all our directors of labor are familiar with the science of their art, and when our men of science are all men applying science.

Rénan, in his autobiography, expresses his conviction that succeeding generations will be taught principally natural sciences, for the reason that the truths learned in their study have more importance to mankind, and have a deeper interest than the facts of history or the accumulated stores of general literature.

Men of Science and men of Art, too, are becoming known and acknowledged as of most importance to mankind, and as the principal reliance of the race in its terrible struggle against poverty, disease, misery, and death. The influence and the power of men who devote themselves to the study of the phenomena of nature, and of those who make useful application of a knowledge of Nature's facts, laws and forces, must inevitably and continually increase so long as civilization shall continue to advance.

The world will finally reward most nobly those who thus most nobly strive to forward its highest aims.

THE RAIL CAMBERING ARRANGEMENT OF THE LACKAWANNA IRON AND COAL CO.

BY

W. K. SEAMAN, SCRANTON, PA.

The subject of the treatment of steel rails after they leave the rolling train is one which has, perhaps, received more of the attention of rolling-mill engineers than any other detail of their manufacture; and the fact that so many diverse means are at present used, is sufficient evidence that none has, as yet, been made wholly satisfactory.

The rail as delivered from the rolling train is substantially straight; but if it now be simply allowed to cool, it assumes a curve, due to the lack of symmetry of its section and its consequent unequal cooling.

To correct this result, the prevailing practice is to give it, by some means, a contrary curve while still hot, so that it will, in cooling, approximate the straight form. Whatever "kinks" may then exist are taken out by the cold-straightening presses or "gags."

Regarding this latter process I quote from a paper read before the Iron and Steel Institute of Great Britain by Capt. Wm. R. Jones, of the Edgar Tompson Steel Works, as follows: "The present plan of straightening by presses is certainly a barbarous one, and will, sooner or later, be superseded by passing the rail through a series of rolls."

All experts are, I believe, agreed that this cold-straightening process is essentially bad; any treatment which contemplates a reduction of its necessary amount is, therefore, worthy of attention.

The "kinks" in a cold rail are traceable to two general causes: first, unequal heating and cooling; and second, to imperfect mechanical manipulation of the product after it leaves the train.

The first of these causes it is practically impossible wholly to overcome.

In the design to be here exhibited, the writer has endeavored fully to meet the second, and, further, to produce a series of machines thoroughly mechanical in detail, no more liable to excessive wear and repair than other rail mill machinery, and capable of being

worked to the full capacity of the most successful rail trains by one or, at most, two men. Cordially inviting their candid criticism, he asks his listeners to be the judges of how far he has succeeded.

In the accompanying drawings (in which all minor constructional details have been omitted), Fig. 1 is a general plan of the entire apparatus ;—those of you who are familiar with the "Gustin" cambering machinery, will observe its similarity as far as the first hot-bed. The details are essentially different, and it is with these that the present paper has chiefly to deal.

In Fig. 1, *A* designates the mouth of the switch, which receives the rail from the finishing rolls whose axis is *MM*—the switch being made to swing on the pivot *T*, so that its mouth can be adjusted to receive the rail from either of the finishing passes, indicated by the dotted lines.

On the switch are secured a series of "idler" guide rolls, *BB*, etc., which guide the rail to the first pair of driven or "grip" rolls, *C*, which forward it thence through the guide rolls B^1 to the second pair of grip rolls, C^1, thence through the guide rolls, B^2, to the third pair of grip rolls, C^2, and so on successively till it reaches the cambering or bending machine, *E*, which delivers it on the hot-bed with the required curve.

It will be seen that a second hot-bed is provided, and that between the rails of the first bed is placed the necessary machinery for transmitting the rail across this bed, and to the second cambering machine and its hot-bed.

Two hot-beds are necessary ; otherwise the capacity of the apparatus for properly cooling the rails would not equal that of the train for rolling them, and the latter machine would necessarily be restricted in output.

It is thought highly advantageous to have two cambering machines for the following reasons:

1st: It is thereby rendered possible to transmit the rail across the first bed, and to the second cambering machine, while it is still straight; the bending roll of the first cambering machine being invariably thrown back, so that this machine acts simply as a pair of grip rolls when the second cambering machine is being used, and the second bed is being filled with rails.

2d. By the use of two cambering machines it is rendered possible to continue work at the rail train, in case of the derangement, from any cause, of either cambering machine. *RR* (Fig. 1)

indicates the main or engine shaft driving the entire arrangement; the saw countershaft (not shown) constantly in one direction by belting from the pulley U; the cambering machines EE^1 and grip rolls II by plain miter-gears, constantly in one direction; the drum shaft II through the reversing friction clutch O in either direction at will, and the grip rolls CC^1,C^2,C^3, through the reversing friction clutch L, in either direction at will.

With the drum shaft, II, we shall have little further to do; its function is simply to slide the rail over the surface of the hot-bed in either direction from the center by means of operating traverse buggies running on top of the rails of the bed.

These buggies are drawn back and forth by endless wire ropes passing over sheaves at either end of the bed, and around the drums, TT, T^1,T^1, at the center several times in the ordinary way. By means of crab couplings on the drum shaft, either pair of drums can be operated at will while the other pair stands still; these couplings being reversed only, of course, when one bed is filled with rails and the other is to be used.

By means of the grip rolls, C^1,C^2 and C^3, the rail is adjusted to and held in the proper position for having its ends cut off by the hot saws DD. These saws are suspended in rigidly trussed swings, and are fed across the rail by a hydraulic cylinder fixed on the central countershaft stand, S^1. The swings and feeding connections are of ample proportions, and are so designed as to insure steadiness and freedom from vibration to the saw mandrel.

Both the friction reversing clutches, O and L, and the hydraulic cylinder feeding the saws, are operated by hand levers, Y,Y^1,Y^2, conveniently arranged upon the elevated working pulpit, V. The operator faces the rail as it lies before the saws, looks toward his right, whence he receives it from the train; in front, when he adjusts it for sawing, and cuts off the ends; and toward his left, when he traverses it across the hot-bed, after it has passed through the cambering machine.

Having thus described the general arrangement, the details, beginning with the "grip" or forwarding rolls ($CC^1C^2C^3$ Fig. 1) will next be considered.

Fig. 2 is a transverse vertical section through the axes of a pair of the rolls; Fig. 3 is a vertical section through yy, Fig. 2.

But one roll, b, of each pair of grips is driven; the other roll, d, runs free on its axle. The driven roll, b, runs in fixed bearings, top and bottom, and receives its motion directly from the line shaft, J,

situated vertically below it, through a pair of miter-gears. The roll d is capable of all the required adjustment for different rail sections in the following manner: As is shown in Figs. 2 and 3, the axle on which it turns is supported top and bottom by the frame of the machine; these two supports have a common axis, while that portion of the shaft around which the roll d revolves is eccentric with them, as distinctly shown in Fig. 3. Now to vary the distance between the two rolls, it is only necessary to turn the shaft E in its supports, through a portion of a revolution, and clamp the shaft firmly in the desired position by the nut N. A square end is provided on the shaft, above the nut, whereby the shaft is turned in its supports and held *while being clamped.*

The rail enters the machine as indicated by the arrow, its weight being carried by the web on the rolls w (Fig. 1), throughout the entire arrangement.

These rolls are so placed that for all common sections of rails their position does not require adjustment of any kind.

The double-cone-shaped casting (Figs. 2 and 3) forms a perfect protection from scale to the bearings and gearing below them; the scale delivering down their sides and away from the machine.

It will be seen that the shaft J, inaccessible, apparently, at first sight, can be removed without disturbing the sole plate I, which is firmly bolted and sulphured to the foundation. Without calling special attention to this point for each machine, it may be here stated that this feature has been embodied in all the details whose positions are over the shaft J. Further: the bearings of the shafts $J\,J^1$ are all in accessible positions for inspection and oiling; this position of these shafts was selected because it did away with so much mechanism necessary in existing arrangements.

The cambering machines, Figs. 4, 5 and 6 (plan and two sectional elevations), situated at E, E^1, Fig. 1, will next be considered.

They are simply combinations in one machine of two pairs of grip rolls, $b\,d$ and $b^1 d^1$, with a bending roll j. One roll, $b\,b^1$, of each pair of grip rolls is driven directly through miter-gears from the shaft J^1; these rolls run in fixed bearings, are in no way adjustable, and are the only driven rolls in the entire machine. The rolls d, d^1 are adjustable by the eccentric arrangement before described; the roll j has precisely a similar means of adjustment, but it is retained in the desired position by the lever n, running over the slotted segment p, and clamped by the nut o.

This segment can be graduated (from practice) for the various

rail sections, and the adjustment of the lever n gives the required variation in camber in a most simple manner.

The ends of the rail (where sharp upward bends are liable to exist as it is delivered from the train) having been invariably sawn off before it reaches the cambering machine, it is admissible to put the upper bearings of the rolls of this machine in a continuous frame, I, *above* the rolls; by this means a much more rigid construction is obtained than is possible where both bearings are *below* the rolls; also, by placing the upper bearings of the shafts above the work they are protected from scale—two important features. The lower bearings and miter-gears are completely protected from scale by the shrouding casting z, which delivers it in all directions, away from the rolls.

One set of the guiding rolls ($B, B^1 B^2 B^3$, Fig. 1) are shown in detail by the upper portion of Figs. 10 and 11, both of which are vertical sections through the axes of the rolls.

As shown in Fig. 1, the several sets of guide rolls, B, B^1, etc., are mounted in appropriate frame castings, but the rolls and their adjustments are precisely like those shown in detail by these figures.

The roll h runs freely on the straight stud r, which extends through a boss on the frame of the machine, and is held in position by the nut s. The adjustable roll i runs free on a stud v, similar to r, except that it has an eccentric offset shown at t, Fig. 11; by turning this stud in its boss, it will be seen that the roll i, revolving about its axle v, will be moved toward or away from the opposite roll h. In each pair of rolls throughout the arrangement, one roll runs about a fixed center, while the other has all the required means of adjustment.

The non-adjustable rolls are in one line, vertically over the shafts JJ and $J^1 J^1$; if, therefore, these are once properly aligned, they will retain such alignment, under all conditions of adjustment of the other rolls, and thereby is obtained a rigidly straight guide for the moving rail.

The essential details as far as the first hot-bed have now been described; the machinery *in* this bed, and for the purpose of transmitting the rail over it to the second cambering machine, will next be considered. The requirements of this mechanism are twofold: first, while the first bed is being used, it must entirely disappear from above the surface of this bed in order to allow of the free transverse motion of the hot rails toward the ends and from the center of the bed, where they are delivered by the cambering machine.

Second, when the second bed is being used, the mechanism must appear above the surface of the first bed in order to grasp and forward the rail across said bed to the second cambering machine and its bed. This mechanism consists simply of one pair of grip rolls (*H*, Fig. 1) and four sets of guide rolls (*GGGG*, Fig. 1) similar to those described, with the addition of means for raising and lowering them above or below the level of the bed, according as to which bed is being used.

Figs. 7, 8, and 9 (plan and two sectional elevations) show the rising grip rolls situated at *H*, Fig. 1. The action of this pair of grip rolls is essentially the same as that of the others; its construction is, however, necessarily different, to allow for the required vertical motion, which is provided for as follows: The lower bearing of the driven roll shaft *c* is fixed in the plate *M* of the machine. The upper bearing of this shaft and the two bearings of the adjustable roll shaft, *e*, are carried in a single casting, *R*, which is capable of vertical motion, carrying the rolls with it, on the four fixed guide-posts, *SSSS*, in a manner similar to that employed for the platen of an ordinary hydraulic or screw press. The driven roll shaft *c*, obtains its motion by means of a "splined" bush, c^*, to which the driven gear is keyed, through which the shaft, *c*, can freely move in the direction of its axis; but from which, by means of a "feather" key, c^2, it obtains its rotary motion.

The casting, *R*, carrying the three bearings, the rolls and attendant parts, is supported through the links, $j^2 j_2$, at the ends of two levers, $K^2 K^2$, which are keyed to the horizontal rock shaft, l^2, running in fixed bearings, on the sole plate. On the opposite ends of these levers, $m^2 m^2$, are the counterweights, *T*, which practically balance the weight of the vertically moving parts.

To raise or lower the pair of grips, it is only necessary to operate the lever, *V*, and, since the parts are balanced, the power necessary to do this is only that due to the friction of the moving parts.

Figs. 10 and 11 show a pair of the tilting guide rolls (*G*, Fig. 1). The two vertical rolls, *h* and *i*, and the carrying roll, *w*, are mounted on a casting which swings about the rock shaft, *L*, and which is counterweighted at *N* and *N*, so that, in operating, the friction only has to be overcome.

FF, Fig. 11, show in section two rails of the first hot-bed, the rolls being shown in their upper position; to lower them, the whole casting supporting them is tilted down by means of the

lever, O, and link, P, to the dotted line indicating their position when the first bed is being filled with rails.

A fixed lug, R, is provided, against which the swinging casting abuts in its upper position, and the rail, always moving in the direction indicated, tends to drive it against this lug; further, by placing the counterweights, NN, out of center as shown, a tendency is produced that keeps the casting against the lug after the rail leaves the rolls.

The several sets of tilting guide rolls and the single pair of rising grip rolls, are all operated by means of a lever, W (Fig. 12), attached by links, P, to convenient points on the several castings as shown, and worked from a point outside the hot-bed.

After having passed through the several sets of grip and guide rolls, $C, C^1, C^2, C^3, B, B^1, B^2, B^3$ (Fig .1), the rail will contain no bends in a *horizontal* plane; if, however, from irregular working of the rolling train, any kinks have been put in the rail in the *vertical* plane, these will still remain in it when it reaches the cambering machine.

To take these kinks out is the function of the straightening machine, situated at P in the general plan, Fig. 1, and which is illustrated by Figs. 13 and 14, the former of which is a side elevation; the latter a vertical section through XX, Fig. 13. The machine contains two *entirely distinct* sets of rolls, as shown in Fig. 14, each composed of five rolls—one set, $GG^1G^2G^3G^4$, acting upon the head of the rail, the other upon its flange.

None of the rolls of this machine are driven, the grip rolls situated on either side of it serving to drive and draw the rail through without further aid.

Each roll is keyed rigidly to its respective shaft: the shafts have their bearings in the eccentric bushes, II^1, etc., which in turn find their support in the frame of the machine. It will now be seen, upon a moment's consideration, that if these eccentric bushes be turned in their bearings, the positions of the centers of the rolls will be altered relatively to one another. From each of the bushes, $I—I^4$, extends an arm $J—J^4$, and from J^2 extends a hand lever K, which connects with the arms J and J^4 by a rod, L, and with the arm J^1, by a rod, M—the arm, J^1 being connected to the arm J^3 by a rod, N. By pushing the lever K in the direction indicated, all the bushes, $I—I^4$, are turned in the direction of the arrows, and the rolls GG^2 and G^4 are moved upward, while the rolls G^1 and G^3 are

moved downward. By pushing the lever in the opposite direction, the motion of adjustment is, of course, reversed.

The adjustment of all the rolls *toward the axis of the rail* is necessary, from the fact that the web of all sections of rails runs on the constant level of the carrying rolls, *ww*, etc. (Fig. 1), and this level must necessarily be maintained through the straightening machine.

In the arms, H^1, etc., are formed segmental slots, *c*, through which screw studs provided with nuts, *e*, extend from the frame of the machine. When the rolls, $G—G^4$, have been adjusted, the nuts, *e*, are screwed down, locking them in the desired position, and thereby retaining the roll centers as required for any given section of rail. Also, screwing down the nuts, *e*, relieves the arms, *H*, etc., and their several connecting links, of all strain; their function being simply to retain the eccentric bushes in their relative positions, when the adjustment of the rolls *is being made.*

It would seem that a machine built upon this plan, but much heavier, might be advantageously tried on cold rails. This, however, is merely a suggestion, on which I should be pleased to hear the views of some of the gentlemen present. By the use of this straightening machine, and the series of aligned guide rolls, the rail is delivered *straight* in both planes to the cambering machine, which gives it its required curve, and delivers it upon the bed. The hot-bed construction adopted with this arrangement is shown by Figs. 15, 16, 17 and 18.

Fig. 15 is a general plan of a portion of the bed. *D*, *D*, *D*, etc., are bed-plates having facing strips on their upper surfaces, which receive the columns supporting the bed rails, *AA*, etc.

To the central row of columns, which are firmly trussed to the adjacent bed-plates, as shown on Fig. 18, the rails, *AA*, are firmly clamped at their middle points, and are free to expand from these points each way toward their ends by being supported on the columns of the rocking construction shown by Figs. 16 and 18. The lower section, C^1, of these columns is firmly keyed to the bed-plates; the upper section, C^2, rocks about the trunnion C^6, which has its bearings in the two *Vs* formed in the lower section. By separating the counterweights, C^4C^4, as shown in Fig. 16, the upper section is prevented from tipping sidewise, while it is free to rock under the expansion of the rails of the bed when the latter is loaded with its burden of hot rails.

Now since the *faced* bed-plates can be set perfectly level when

they are put down, we can, by facing the bottoms of all the columns to a common template, measured from the rough surface c^5, insure a perfect level to the upper surface of the hot-bed, with the single-faced joint at the foot of the columns.

Care, however, must be taken to keep the sections of columns measured, in pairs together, otherwise the variation in the castings will affect the accuracy of the work.

The trunnion C^6 and its *Vs* are rough cast, and are protected from scale by the projecting wings, C^2, Figs. 16 and 18.

The columns are attached to the bed-plates by keys and pins, all of which are fitted in "cored" holes, making a comparatively inexpensive construction. The bed is made unusually high, in order to allow a free circulation of air beneath it; thereby obtaining an approximately equal cooling effect, upward and downward.

The details of the arrangement having been thus described, the following claims are made for it:

1st. The maintenance of perfect parallelism between the axes of the rolls in all conditions of adjustment.

2d. Dispensing with the necessity of different sets of change rolls for the various rail sections.

3d. The means of obtaining a variable camber for different rail sections, with but the one simple adjustment of the lever of the bending roll of the cambering machine over its graduated arc.

4th. In the cambering machine, by the use of the continuous upper frame *above* the rolls, a much more rigid construction than has been hitherto obtained.

5th. The efficient provision for the exclusion of scale from bearings and gearing.

6th. A rigidly straight guide for the moving rail by making one of each pair of rolls run about a *fixed* center, while the opposite adjusts toward it.

7th. The minimum of necessary labor for operating.

8th. The minimum of necessary driving gearing and shafting.

9th. The provision for taking vertical kinks out of the rail by the use of the straightening machine; and,

10th. The provision of a hot-bed that will remain level under the variable temperatures to which it is subject.

The strongest criticism that has been urged against this arrangement is, that the machinery must be well maintained, and that it will therefore rapidly deteriorate in the rough usage it will receive in the average rail mill. In replying to this I cannot do better than

quote the words of the late A. L. Holley, Esq. In a synopsis of his lectures, delivered at Columbia College in 1879, he says: "An iron-works is a comparatively good place to maintain good engines. The objection of bad attendance is simply atrocious"

I ask, if true of engines, why not true as well of this machinery? It needs fair attention, nothing more; and I claim that one competent man, to have exclusive charge of it, is all that is necessary to its successful manipulation.

It may be well to here call attention to the facts which an inspection of the drawings will show: 1st, that any one of the series of machines can be introduced into existing arrangements, independently of the others. Particularly is this the case with the cambering machine, forwarding rolls and straightening machine; 2d, that the arrangement as a whole can most readily be adapted to the handling of double, triple or quadruple lengths, in the "direct rolling" process now, to a limited extent, coming into vogue in this country.

In conclusion the writer would say that the Lackawanna Iron and Coal Co. now have the whole arrangement in course of construction agreeably to the designs that have been here shown; it will be erected at the earliest available stoppage of the rail mill, a somewhat uncertain date, as rolling-mill superintendents will readily understand.

Through the kindness of Mr. C. F. Mattes, the General Manager of the company, who has throughout rendered every available aid, those especially interested in the subject are cordially invited to visit Scranton for an inspection of its practical working after it is put into operation.

DISCUSSION.

Mr. Durfee.—I would like to ask the author of the paper what provision he has made in the machine, if any, for this condition of facts? It is well known that rails are never finished at a uniform temperature, when compared one with another. I presume it is the intention to give by this machine a definite curve to the hot rails, which is of such character as will cause the rails to become straight when cold. Now if such is the purpose of the machine, every rail must pass through it at a temperature suited to the degree of curvature in order to uniformly produce straight rails, which uniformity of temperature cannot practically be maintained.

Mr. Seaman.—In reply, I would say that it is not expected that

this machinery will produce a perfect product. It only points toward an improvement, and if we obtain such improvement in the product with a much smaller force to operate it, we will do a good thing. We cannot expect to have straight rails when they get cold, on account of the very reasonable suggestion made that it is impossible to maintain a uniform temperature.

Mr. Durfee.—Then, Mr. President, all the rails will have to pass some one's inspection, and all those which are not straight will have to be straightened in the ordinary way. Now, while it is known that one sturdy straightener, with a boy as an assistant, will straighten 70 tons of rail in one day, it does seem to me that this is a very large amount of machinery to get rid of that amount of handwork.

Mr. Seaman.—This machinery does not contemplate doing away with the straightening process. It contemplates the handling of the rail from the train to the straightening press. During that journey of the rail from the train to the straightening press, it is under the control of one man. I have visited several works where they were in process of getting this thing up. At one I have seen the rails dragged from the rolling train to the hot-bed by four men. At other works this same general arrangement is used, but the details are essentially different, and the details are what have given the trouble; that is, they are not mechanical. I cannot see anything unmechanical in this.

Mr. Durfee.—I think, Mr. President, that the author of this plan has shown a great deal of ingenuity in his general mechanical arrangements. But my objection is this, that there is a vast amount of machinery to do very little work comparatively. Two men, or one man and a gag boy, will straighten cold 70 tons of rails in a day. I have had that amount of work done repeatedly with that force. As regards the handling of the rail from the train to the hot-bed, in many mills simple arrangements are devised for that purpose, and the arrangement proposed here with buggies traveling to carry the rails lengthwise from the hot-beds is, I should think, very satisfactory indeed; but the machinery for getting the rail to that handling arrangement (and, really, I think it appears that that is all it does), it seems to me, is unnecessarily elaborate and expensive.

Mr. Hunt.—Not having had the pleasure of hearing the description of the machinery, I cannot express an opinion of Mr. Seaman's arrangement. But in answer to my friend, Mr. Durfee, I would say that I think one of our greatest troubles in rail manufacture

to-day, is to get a perfectly straight rail; that is, they will put some more kinks into the rail that passes under their press. Railroad engineers are becoming more and more particular, so that we are in constant discussion in regard to rails, they thinking they are not good enough and we insisting they are a little too good. The hot straightening is a point that will bear the putting in of a good deal of machinery.

Prof. Robinson.—One point should not be overlooked in the discussion, and that is that in practice we have the trouble of the breakage of rails. The first bend is one step toward the destruction of the rail, if it is made when the rail is cold, whereas if it is hot there is less injury to the rail by bending it. Any roadmaster will tell you he would prefer to have his rails straightened hot, in preference to being bent cold.

Mr. Durfee.—The simple system of bending rails hot on a curving plate allows those rails to cool with very little curvature in them; as little, I think, as would result from all this machinery, if the work is carefully done. It is the constant practice in mills for rails to come from the train to be carried by some means, automatically in many mills, to the straightening plates. They are there sawed off and curved to a definite curvature and the curvature which is found by experience to be that which will enable a rail of average temperature to cool as straight as possible. I think that the ordinary system of practice is quite as satisfactory as this expensive mass of matter would be.

Mr. Seaman.—In reply to the last observation, I would say that the various systems of cold straightening plates compel every rail, whether it weighs 56 pounds to the yard or 30, to take the same curve. Now does it look reasonable to any one familiar with the business that those two sections, varying as they do 26 pounds in the length of one yard, will have the same variation in cooling that is due to their difference in weight?

Mr. Durfee.—In reply to that observation, I would say that I have constructed five or six rolling mills, and I have never yet built one in which I was not able to vary the curvature of the hot rail at pleasure.

Mr. Seaman.—I have seen two of that nature. In the Lackawanna Coal and Iron Company's Works at Scranton we have an arrangement to change that adjustment, but it is never used.

Mr. Durfee.—I will describe a very simple means I adopted and found to work very satisfactorily. A couple of rails were rolled

and allowed to take such curvature in cooling as they naturally would. Those two rails were then bolted together with their flanges uppermost, and used as a curving plate. To change the curvature for different sections of rail, little pieces of bent sheet iron of different sizes made to clip the flanges of the rail were slid on when the section of rail being made was changed.

Mr. Strong.—I rise to the point of order that the machine which he has used is not before the Society. I am not a rolling-mill engineer, and as to the merits of this machine, I would not like to give my opinion; but as to the mechanical details carried out, and as to the general way in which the gentleman has described the machine I must compliment him.

Mr. Durfee.—I do not consider that the point of order is well taken. The author of the paper said that it was not reasonable to suppose that rails of varying section could be curved on the same curving plate and cooled in a straight line. My remarks only tended to show that in my own practice I never made such a construction; that I did not regard such a construction as necessary, and to explain very briefly and simply the construction I had adopted. I had no intention of advocating my own plan in preference to any one else's, and no intention of criticising unnecessarily or severely the plan which the gentleman has so very ably elaborated. I have no feeling in the matter at all. I only wish to present the facts which I think are essential to the operation in view.

The President.—The gentleman was entirely in order. He has a perfect right to make a comparison of that and other machines.

Rail Cambering Arrangement

designed for the

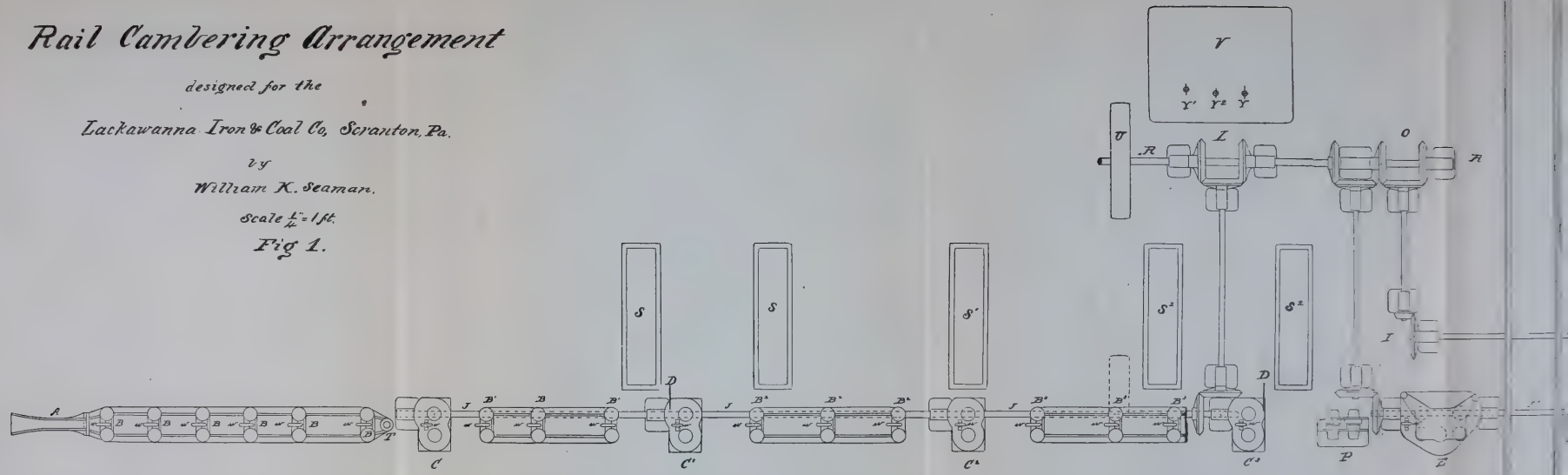
Lackawanna Iron & Coal Co, Scranton, Pa.

by

William K. Seaman.

Scale $\frac{1}{4}$" = 1 ft.

Fig 1.



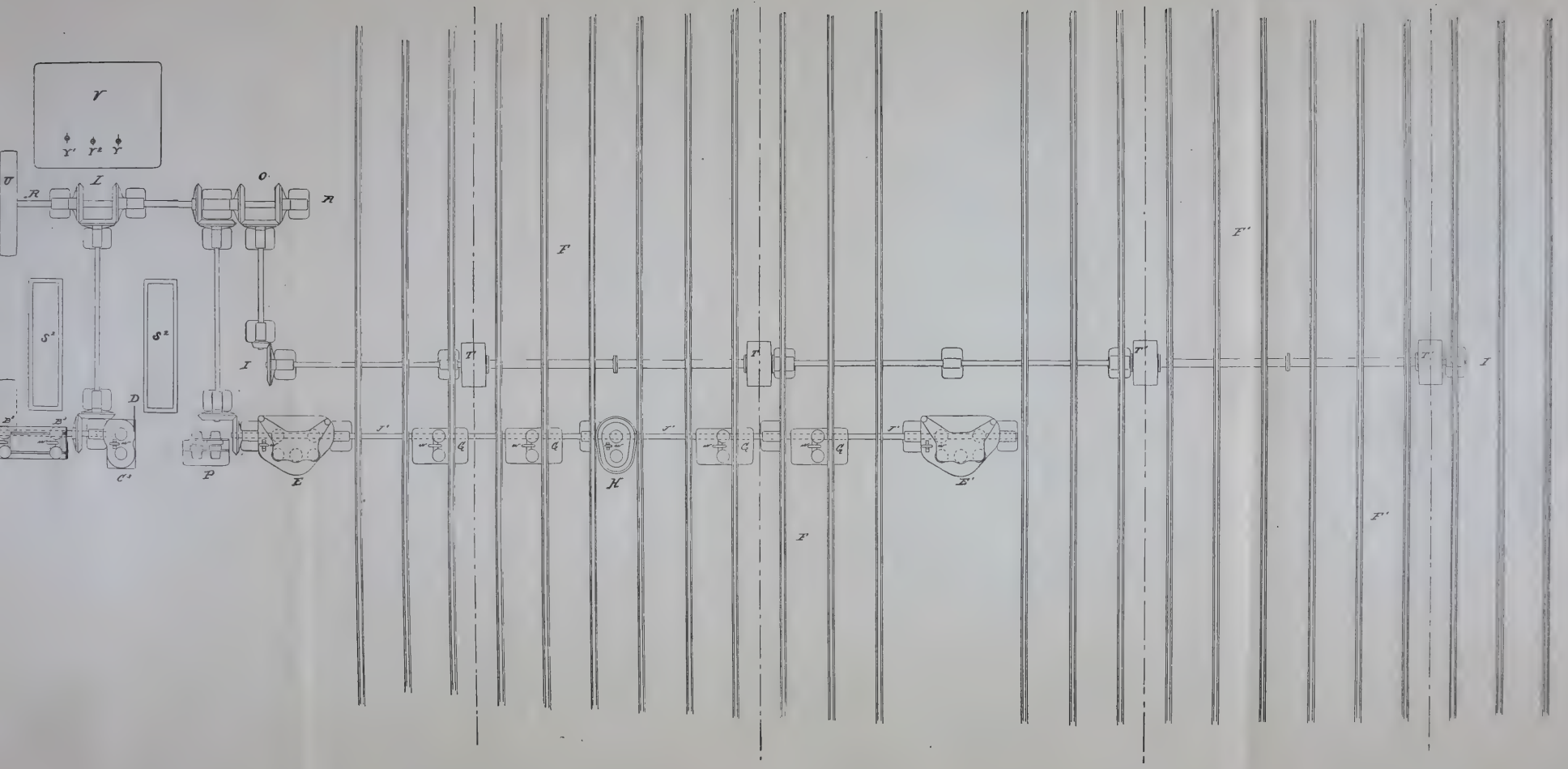

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Fig 2.

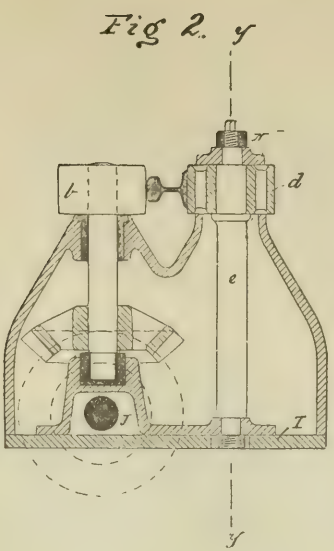
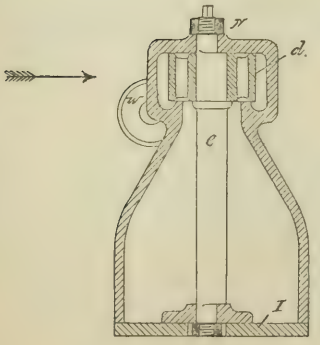
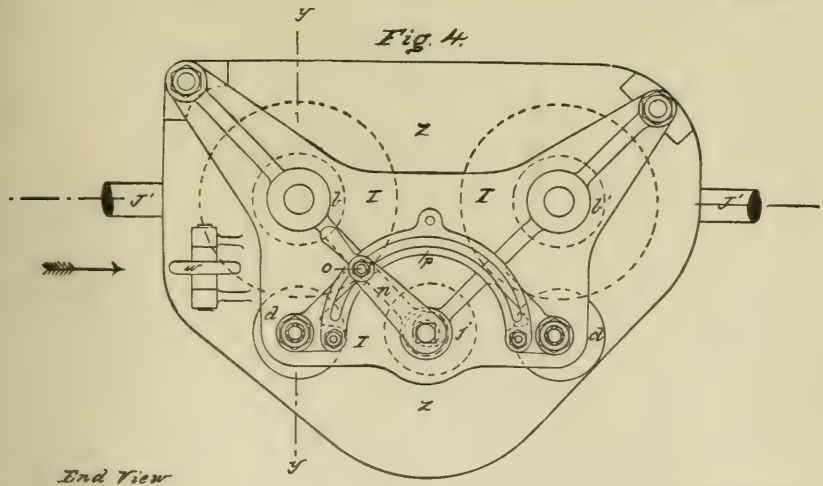


Fig 3.



Grip Rollers. (C, C', C², C³ Fig 1.)

Fig. 4.



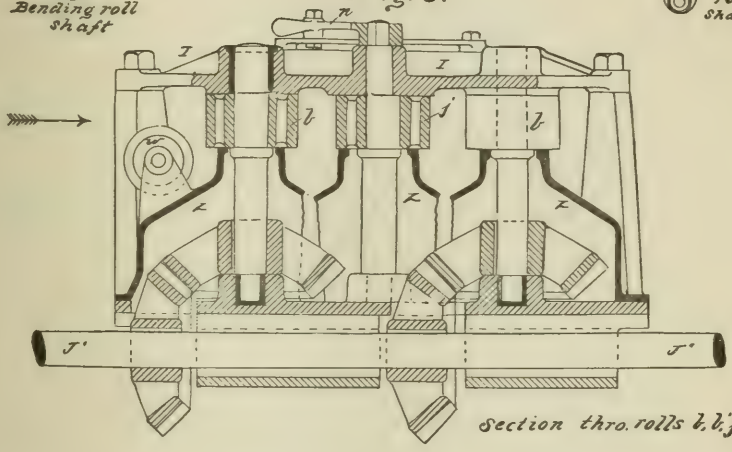
End View

Bending roll shaft

End View

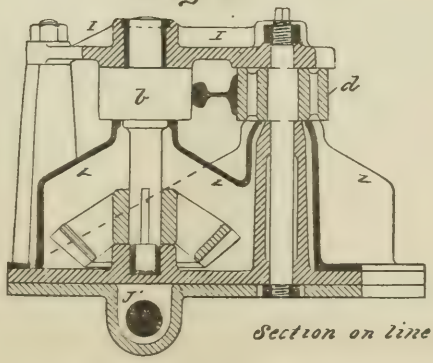
Grip roll, shaft.

Fig. 5.



Section thro. rolls b, b', j.

Fig. 6.



Section on line yy.

Cambering Machine. (E, E' Fig 1.)

Fig 7.

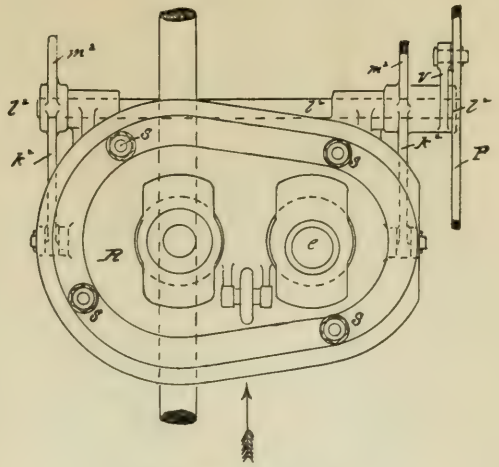


Fig 8.

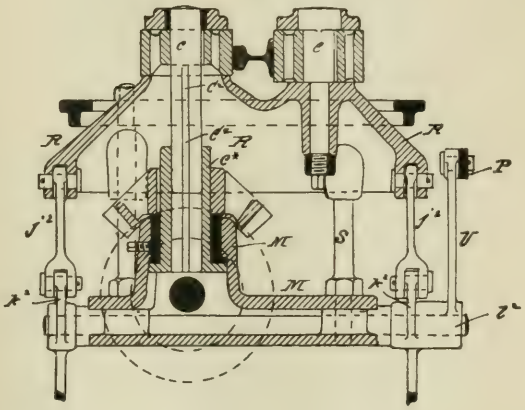
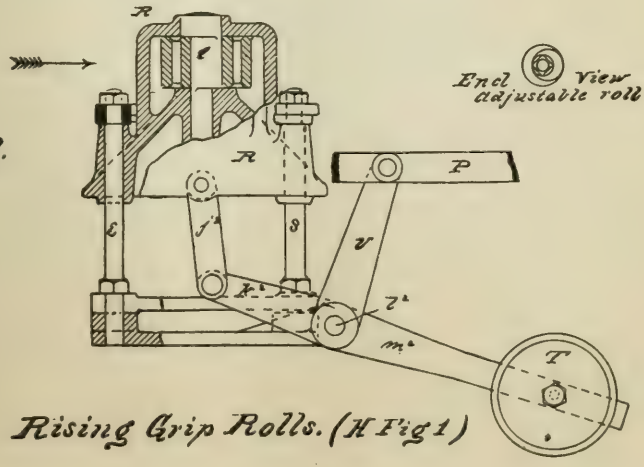


Fig 9.



End View adjustable roll shaft.

Rising Grip Rolls. (H Fig 1)

Fig 10.

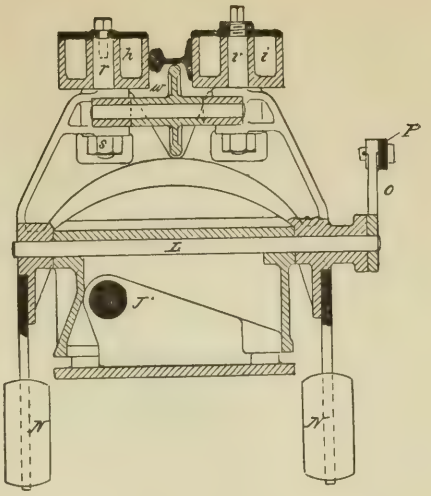
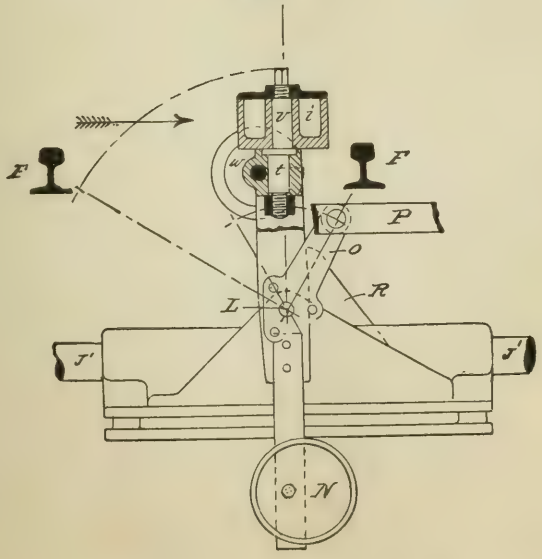


Fig. 11



Tilting Guide Rolls. (Q, Q, Q, Q. Fig 1)

Fig 12.

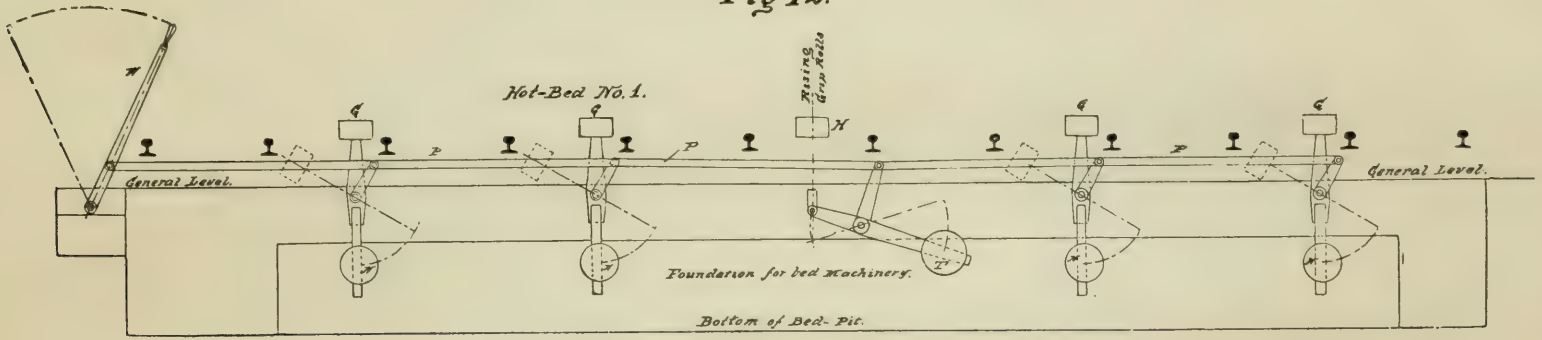

Hot-Bed No. 1.
Rising Guide Rolls
H
G
P
General Level.
General Level.
Foundation for bed Machinery.
Bottom of Bed-Pit.

Fig 13.

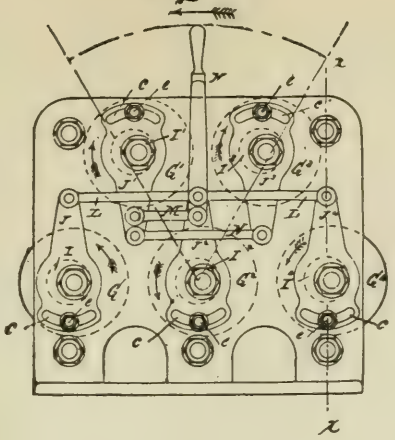
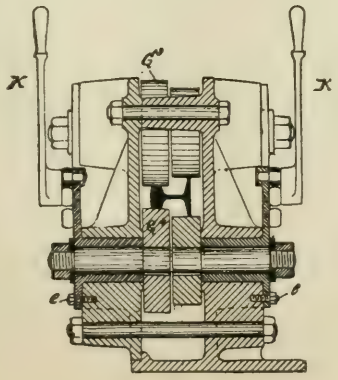


Fig 14.



Hot-Rail Straightening Machine. (Fig 1)

Fig 15.

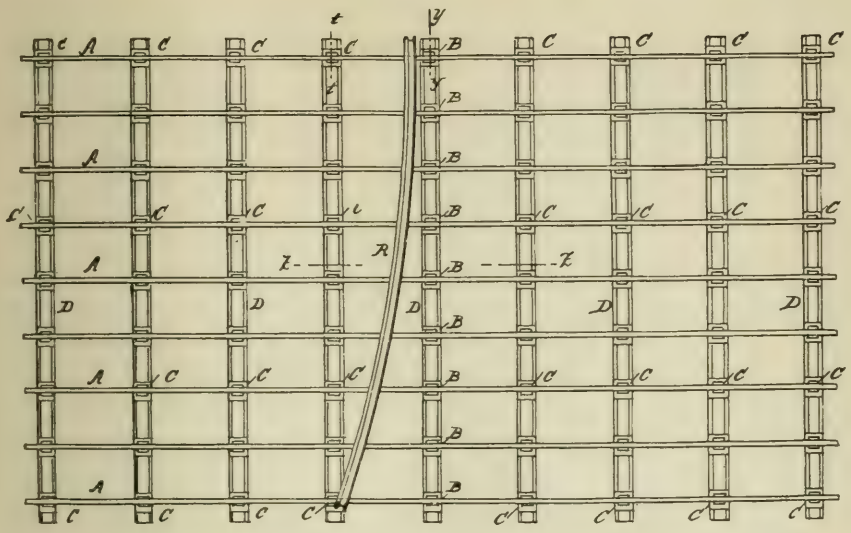


Fig 16

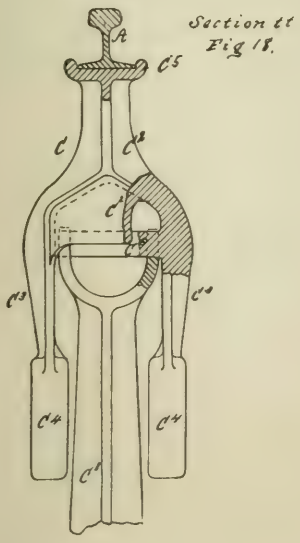
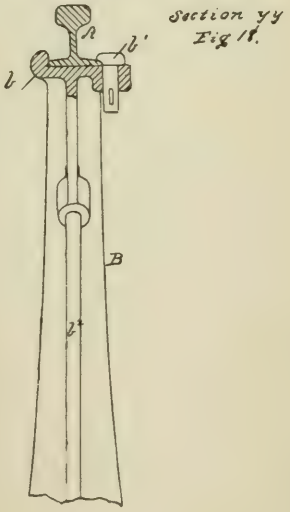


Fig 17



Hot-Bed (F. F.' Fig 1)

Fig. 16.

Hoff-Beck. (Fig. 1.)

AN ACCOUNT OF CERTAIN TESTS OF THE TRANSVERSE STRENGTH AND STIFFNESS OF LARGE SPRUCE BEAMS.

BY

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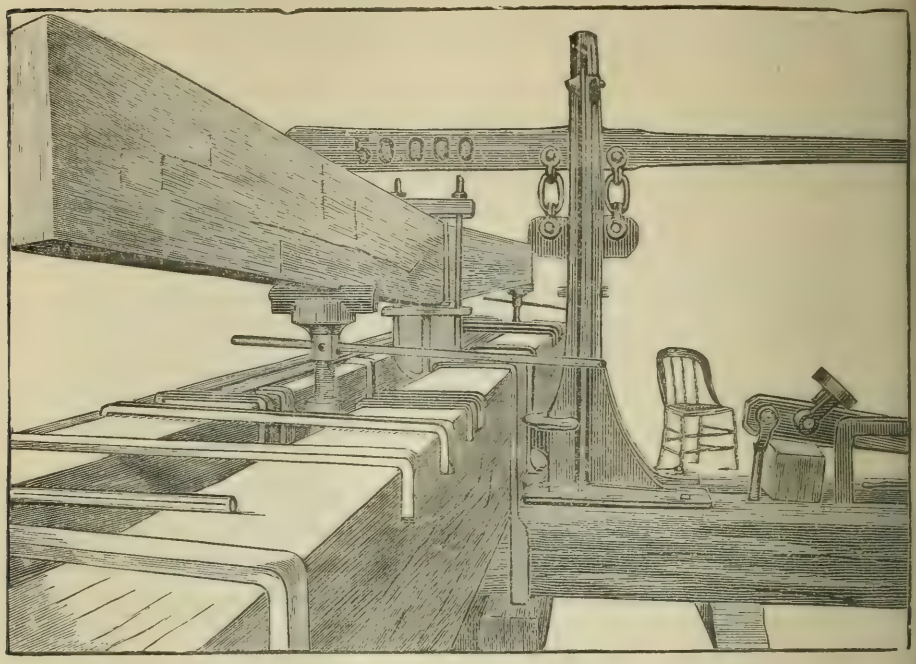
I beg leave to call your attention to the results of certain tests of the transverse strength and stiffness of full-size spruce beams, carried on by members of my classes in my laboratory at the Massachusetts Institute of Technology. The machine with which they were made is a 50,000-pound machine, and is capable of testing beams twenty-five feet long and under, as well as many of the framing joints used in practice.

It consists, as shown in the cut, of a compound lever, hung in a cast-iron frame, to which is connected, by means of a steel rod and turn buckle, one end of a lever, of equal arms, placed below, this lever having a 12-inch leverage, and being connected at its other end by means of a chain with the yoke shown in the cut. Two hard pine beams, each 20 inches deep, 10 inches wide, and 26 feet long, are laid across the timbers of the machine in such a way that the chain already referred to is midway between them. Two common jack-screws, each in a pair of wrought iron stirrups, are placed at a distance apart depending upon the span of the beam to be tested, the latter being placed, as shown in the cut, upon the jack-screws and under the yoke. The jack-screws are then screwed up, and the beam to be tested is thus raised at its two ends, and hence loaded at the point where the yoke is attached.

It was in operation about two months last session, and has been in operation about one month this present session. During that time we have tested about thirty specimens for breaking strength and about fifteen for deflection. The breaking has been effected as rapidly as could be done, consistently with the determination of the deflections, and the deflections under various loads were measured within a very short time after the application of the loads. In short, no experiments have thus far been carried on to determine the effect of time upon these quantities, though some will be made

very soon. It was also deemed best to keep to one kind of timber until we should have a sufficient number of tests to warrant us in drawing a conclusion as to the average value of the modulus of



rupture, and of the modulus of elasticity of that kind of wood; and spruce was selected, as a wood that is very much used in building. Experiments are now in progress in my laboratory to determine the same quantities for yellow pine.

The results that were obtained last session are shown above the double line in the accompanying table, and those obtained this present session, below.

At the beginning of this session these tests were continued, with the following objects in view:

1. Inasmuch as the lumber had, last session, been selected either by a carpenter, without reference to testing, or had been simply ordered at the yard, directions being given to the dealer to send merchantable stock, it seemed best that I should go the yards myself and select from the piles some of the best and some of the average of what was on sale as merchantable stock, and thus that we should be able to speak with certainty about the values of the modulus of rupture and modulus of elasticity of such lumber.

2. Inasmuch as last year we had had only three determinations of the modulus of elasticity, it was desirable to obtain more values, and thus to be able to determine an average value.

3. It was desirable to see how far, in the light of what had already been done, we should be able to judge of the modulus of rupture by simply inspecting a piece of timber, and to endeavor also to train the students, to some extent, to have this ability.

That the values of the modulus of rupture which we have obtained should differ very considerably from those given in our text-books and engineers' handbooks, and deduced from tests of small pieces, I need not tell a company of engineers; but, as you may not carry in your minds the precise figures given by different authorities for the modulus of the rupture of spruce, I will place them here:

Hatfield gives as mean value .	.	9,900 lbs. per sq. in.	
Rankine " " .	.	11,100	"
Laslett " "	.	. 9,045	"
Trautwine " " .	.	8,100	"
Rodman " "	.	. 6,168	"

Trautwine advises for use to deduct one-third in the case of knotty and poor timber.

NO. OF TEST.	WIDTH AND DEPTH IN INCHES.	DISTANCE BETWEEN SUPPORTS. Ft.	In.	MANNER OF FIXING THE ENDS AND LOADING.	BREAKING WEIGHT IN POUNDS.	MODULUS OF RUPTURE IN LBS. PER SQ. IN.		MODULUS OF ELASTICITY IN LBS. PER SQ. IN.	REMARKS.
1	2 x 12	6	8	Framed at ends	6,304				
2	4 x 12	6	8	Header	10,338				
3	2 x 12	15		Load at middle	5,794	5,432		1,237,215	
4	2 x 9	6	7.5	" "	7,227	5,320		1,067,893	
5	2 x 12	15		" "	5,586	5,237			
5 (*a*)	2 x 12	7		" "	8,982				
6	2.75 x 9	6	8	" "	7,586	4,082		938,453	
7	3 x 9	4		" "	11,086	3,285			
8	3 x 9	10		" "	6,086	4,508			
9	3 x 9	15		" "	5,086	5,651			
10	$3\frac{7}{8}$ x 12	20		" "	6,586	4,253			
11	2.5 x 13.5	10		" "	9,585	3,787			
12	3.75 x 12	16		Load 4'.5 ft. from one support	7,585	3,271			
13	3.75 x 12	16		Ditto, mortised	9,085				
14	7 x 2	7		Load at middle	1,944		8,748		Selected stock.
15	1.75 x 6.75	7		" "	4,785		7,562		Selected stock.
16	3 x 9	6	8	" "	9,985	4,931			
17	3 x 9	6	8	Load at 4 points, 16 ins. apart	16,744	4,961			
18	3.9 x 12	16		Load 4'.5 ft. from one support	12,585	5,218			
19	2 x 12	14		Load at middle	4,404	3,854		1,482,645	
20	2 x 12	14		" "	5,108	4,469		1,588,548	
21	$3\frac{5}{16}$ x 12	14		" "	8,627	3,834		1,187,073	
22	$3\frac{7}{8}$ x 12	14		" "	12,545	5,666		1,332,715	
23	$3\frac{7}{8}$ x $12\frac{1}{4}$	14		" "	6,917	2,995		897,961	
24	3 x $11\frac{7}{8}$	14		" "	8,927	5,442		1,572,470	
25	2 x $9\frac{3}{4}$	14		" "	3,198	4,239		1,460,620	
26	$2\frac{3}{4}$ x 12	14		" "	6,819	4,339		1,396,667	
27	$1\frac{15}{16}$ x 10	14		" "	4,306	5,601		1,355,860	
28	$4\frac{1}{8}$ x 12	18		" "	8,829	4,816		1,397,136	
29	4 x $12\frac{1}{8}$	18		" "	8,324	4,586		1,259,224	
31	$3\frac{1}{8}$ x 12	18		" "	7,721	5,559		1,231,498	
						25)115,336		15)19,405,978	
						4,613 = Av. mod. of rupture.		1,293,732 = Av. mod. of elasticity.	

As a result of the tests thus far made in my laboratory, it seems to me safe to say, that if our Boston lumber yards are to be taken as a fair sample of the lumber yards in the case of spruce, that if such lumber is ordered from a dealer of good repute, no selection being made except to discard such pieces as might be classed as culled timber, *i. e.*, that which is rotten or has holes in it, that 3,000 pounds per square inch is all that could with any safety be used for modulus of rupture, and even this might err in some cases, in being too large. 2. That if the lumber is carefully selected at any one lumber yard, so as to take only the best of their stock, it would not be safe to use for modulus of rupture a number greater than 4,000, and if we required a lot of spruce lumber which should have a modulus of rupture of 5,000 it would be necessary to select a very few pieces from each lumber yard in the city.

Next, as to the modulus of elasticity: Until the beginning of this session we had made only three experiments on this subject, and these gave as an average 1,081,187: those made this autumn have contributed to raise this value somewhat, as will be seen from the table, where we obtain an average of 1,293,732.

Of course it is naturally to be expected that time tests will give much smaller values for both modulus of rupture and modulus of elasticity.

As to the variations of the values shown in the table, they are considerable, and depend upon the quality of the lumber, *i. e.*, upon the number and location of the knots, the shakes and cracks, that are so commonly found at the heart of timber, also upon the degree of seasoning, although it is my opinion that the increase of strength due to this latter item has often been overestimated. Knots near the middle of the span act very prejudicially, whether they are at the top or at the bottom, and by saying near the middle of the span I mean to include a very considerable range. It is impossible, however, to describe the mode of judging correctly, from inspecting a stick, what will be its modulus of rupture, and this ability can only be acquired by practice, and this very practice is one of the benefits that it is hoped to enable the students to gain to a greater or less degree.

As to the relation between the modulus of rupture and the modulus of elasticity, while it is generally true that those pieces that have a high value of the one have a high value of the other, and *vice versa*, nevertheless, I have not been able thus far to form any definite idea of the connection between them, at least such as to enable

one to attempt to predict the modulus of elasticity from the appearance of the piece. Perhaps further experiments may satisfy this want, and as to the desirability of satisfying it no one can have any question, for the stiffness of beams is, or ought to be, as prominent a question to builders as their breaking strength.

We have already made three, and shall make quite a number of experiments on the strength of framing joints, such as headers, trimmers, etc., in regard to which we have thus far been entirely devoid of any experimental knowledge.

As to the method of fracture: While the most usual fractures in spruce beams have occurred either by tension or compression, or a combination of the two; nevertheless in some cases the beams have been split from the middle to one end, along or near the neutral axis; and while the experiments where this kind of fracture has occurred are not sufficient in number to warrant definite conclusions as yet, nevertheless it is an element that is forcing itself very strongly upon our attention as one that must be taken into account in practice.

A noticeable instance of this kind is to be found in the case of beam No. 22, another in beam No. 24, and a third in beam No. 31, which gave way in that manner.

[At the meeting a number of photographs of the fractures obtained were exhibited and commented upon.]

TABLE OF TESTS.

The following are the records of the tests made during the first month of the present session by students in the Department of Applied Mechanics of the Massachusetts Institute of Technology. In these tables, as far as the deflections are concerned, the first load is assumed as the starting point, the deflection under that load being counted zero.

The deflections are recorded to the 10,000th of an inch, as the measurements were made with a micrometer screw that could be read to that degree of accuracy, and hence it was thought best to give the results as they were obtained, although it is not claimed that change of temperature or other disturbing causes, which would be inappreciable as far as any practical result is concerned, may not cause so great a variation as to render it unnecessary to read to such a degree of accuracy.

The spruce, with the exception of Nos. 22 and 23, was cut in the spring of 1882, and brought from Bangor, Me. Nos. 22 and 23 were

cut in 1881. The students making the tests hand in the reports of the same, and make the necessary computations of modulus of rupture, modulus of elasticity, etc. The values given in the tables have been re-computed by my assistant, Mr. Edward F. Ely.

The number given as the "Max. intensity of shear at neutral axis" is that which would be obtained by computing it from the breaking load in accordance with the ordinary theory of beams.

No. 19.—Spruce Joist, 2 in. by 12 in. Span 14 feet. Loaded at center. Ordinary stock.

Tested by Messrs. Tompkins and Gustin.

Load in lbs	Deflection in inches.	Differences.	
485	.0000		
686	.0473	.0473	Rested over night.
510	.....	.....	Load on next morning.
485	.0000	.....	Began new set of readings.
686	.0343	.0343	
887	.0825	.0482	
1,088	.1284	.0459	
1,088	.1309	.....	After 1 hour.
1,289	.1764	.0455	
3,600	.....	.....	Cracks opened near center above neutral axis.
4,103	.....	.....	Bulging on east side at top. At center, top slewed to west.
4,404	.....	.....	Breaking load.

Fracture occurred within an hour after application of breaking load.

Line of fracture followed the knots.

Modulus of rupture = 3,854 lbs. per square inch.

Mean deflection for 201 lbs. = .0465.

Modulus of elasticity = 1,482,645 lbs. per square inch.

Maximum intensity of shear at neutral axis=138 lbs. per square inch.

No. 20.—Spruce Joist, 2 in. by 12 in. Span 14 feet. Loaded at center. Not many knots.

Tested by Messrs. Tompkins and Gustin.

Load in lbs.	Deflection in inches.	Differences.	
485	.0000		
686	.0431	.0431	
887	.0885	.0454	
1,088	.1303	.0418	
5,813	.....	.....	Twisted badly in spite of bracing, and load fell off rapidly, it being impossible to keep this load on.
5,108	.....	.....	Breaking load.

Modulus of rupture = 4,469 lbs. per square inch.

Mean deflection for 201 lbs. = .0434.

Modulus of elasticity = 1,588,548 lbs. per square inch.

Maximum intensity of shear at neutral axis = 160 lbs. per square inch.

No. 21 Spruce Joist, $3\frac{5}{16}$ in. by 12 in. Span 14 feet. Loaded at center. Ordinary stock.

Tested by Messrs. Tompkins and Gustin.

Load in lbs.	Deflection in inches.	Differences.	
686	.0000		
1,088	.0546	.0546	
1,490	.1033	.0487	
1,892	.1654	.0621	
2,294	.2192	.0538	
2,696	.2858	.0666	
3,098	.3397	.0539	
3,500	.4030	.0633	
3,902	.4644	.0614	
4,304	.5256	.0612	
4,706	.5898	.0642	Left over night.
4,203	.5845	.....	Next morning.
4,706	.6529	.....	Load increased to 4,706 again.
4,404	.....	.....	Next day.
5,610	.....	.....	Braced the stick.
8,627	.....	.....	Breaking load after carrying 15 minutes.

Modulus of rupture = 3,834 lbs. per square inch.

Mean deflection for 402 lbs. = .0590.

Modulus of elasticity = 1,187,073 lbs. per square inch.

Maximum intensity of shear at neutral axis = 137 lbs. per sq. in.

No. 22.—Spruce Joist, $3\frac{7}{8}$ in. by 12 in. Span 14 feet. Loaded at center. Lower part of tree. Very free from knots. Had been seasoning on the wharf about one year.

Load in lbs.	Deflection in inches.	Differences.	
485	.0000		
887	.0534	.0534	
1,289	.1052	.0518	
1,691	.1583	.0531	
2,495	.2665	.1082	
3,299	.3748	.1083	
4,103	.4810	.1062	
4,907	.....	.....	Left over night.
4,203	.....	.....	Next morning.
12,545	.....	.....	Breaking load. Beam broke by tension and afterward by shearing along the neutral axis. Shear extended from center to one end, and pieces slid by one another about $\frac{7}{16}$ inches.

Modulus of rupture = 5,666 lbs. per square inch.

Mean deflection for 402 lbs. = .0534.

Modulus of elasticity = 1,332,715 lbs. per square inch.

Maximum intensity of shear at neutral axis = 202 lbs. per sq. in.

No. 23.—Spruce Joist, $3\frac{7}{8}$ in. by $12\frac{1}{4}$ in. Span 14 feet. Loaded at center. Upper part of same tree as No. 22. Very knotty. Had been seasoning on the wharf about one year.

Tested by Messrs. Tenney and Mansfield.

Load in lbs.	Deflection in inches.	Differences.	
485	.0000		
887	.0819	.0819	
1,289	.1457	.0638	
1,691	.2204	.0747	Left over night.
1,425	.....	.....	Next morning.
1,691	.2569	.....	Raised load again.
2,093	.3269	.0700	
2,495	.4017	.0748	
2,897	.4828	.0811	
3,299	.5536	.0708	
4,103	.7073	.1537	
4,907	.....	.....	Left on for half an hour, during which time load fell off to 4,202 ; beam splitting and cracking at a large knot on lower edge near center of span.
6,917	.....	.....	Breaking load (knot causing break about 15 inches from center).

Modulus of rupture = 2,995 lbs. per square inch.

Mean deflection for 402 lbs. = .0745.

Modulus of elasticity = 897,961 lbs. per square inch.

Maximum intensity of shear at neutral axis = 108 lbs. per. sq. in.

No. 24.—Spruce Joist, width $3\frac{1}{16}$ in. at bottom, $2\frac{3}{8}$ in. at top, depth $11\frac{3}{8}$ in. Span 14 feet. Loaded at center. Not many knots.

Tested by Messrs. Scott and Foran.

Load in lbs.	Deflection in inches.	Difference.	
485	.0000		
887	.0603	.0603	
1,289	.1247	.0644	
1,691	.1835	.0588	
2,093	.2485	.0650	Left 15 hours, when load had fallen to 1,766 lbs.
2,093	.2742		
2,495	.3285	.0543	
2,897	.3870	.0585	
3,299	.4521	.0651	
3,701	.5189	.0668	
4,103	.5746	.0557	
8,927	.....	.....	Breaking load. Broke by shearing along neutral axis. Split open about $1\frac{1}{2}$ inches.

Modulus of rupture = 5,442 lbs. per square inch.
Mean deflection for 402 lbs. = .0610.
Modulus of elasticity = 1,572,470 lbs. per square inch.
Maximum intensity of shear at neutral axis = 190 lbs. per sq. in.

No. 25.—Spruce Joist, 2 in. by $9\frac{3}{4}$ in. Span 14 feet. Loaded at center. Ordinary stock.

Tested by Messrs. Scott and Foran.

Load in lbs.	Deflection in inches.	Differences.	
485	.0000		
887	.1625	.1625	
1,289	.3342	.1717	
1,691	.5280	.1938	
3,198	.....	.....	Breaking load, by compression at top and tension at bottom.

Modulus of rupture = 4,239 lbs. per square inch.
Mean deflection for 402 lbs. = 1,760.
Modulus of elasticity = 1,460,620 lbs. per square inch.
Maximum intensity of shear at neutral axis = 123 lbs. per sq. in.

No. 26.—SPRUCE JOIST, $2\frac{3}{4}$ in. by 12 in. Span 14 feet. Loaded at center. Ordinary stock.

Tested by Messrs. Tenney and Mansfield.

LOAD IN LBS.	DEFLECTION IN INCHES.	DIFFERENCES.	
485	.0000		
887	.0534	.0534	
1,691	.2050	.1516	
2,495	.3610	.1560	
3,299	.5025	.1415	
5,610	.....	.....	Cracked somewhat.
5,713	.....	.....	Cross-grained fiber at bottom tore apart.
5,914	.....	.....	A sharp crack was heard and a long split appeared.
6,819	.....	.....	Breaking load.

Modulus of rupture = 4,339.

Mean deflection for 402 lbs. = .0718.

Modulus of elasticity = 1,396,667 lbs. per square inch.

Maximum intensity of shear at neutral axis = 155 lbs. per square inch.

No. 27.—SPRUCE JOIST, $1\frac{15}{16}$ in. by 10 in. Span 14 feet. Loaded at center. Not many knots.

Tested by Messrs. Tenney and Mansfield.

LOAD IN LBS.	DEFLECTION IN INCHES.	DIFFERENCES.	
485	.0000		
887	.1724	.1724	
1,289	.3272	.1548	Beam tipped and braces were put in at ends beyond the straight edges.
1,691	.5441	.2169	Wedge was used on west side to keep straight edge close to the beam.
4,306	.....	.....	Breaking load.

Modulus of rupture = 5,601 lbs. per square inch.

Mean deflection for 402 lbs. = .1814.

Modulus of elasticity = 1,355,860 lbs. per square inch.

Maximum intensity of shear at neutral axis = 167 lbs. per sq. in.

No. 28.—Spruce Joist, width 4¼ in. at bottom, 4 in. at top, depth 12 in. Span 18 feet. Loaded at center.

Tested by Messrs. Tenney and Mansfield.

Load in lbs.	Deflection in inches.	Differences.	
485	.0000		
887	.1049	.1049	
1,691	.2999	.1950	
2,495	.5030	.2031	
3,299	.7033	.2003	
3,701	.8136	.1103	
4,103			
8,829	.....	.....	Breaking load.

Modulus of rupture = 4,816 lbs. per square inch.
Mean deflection for 402 lbs. = .1017.
Modulus of elasticity = 1,397,136 lbs. per square inch.
Maximum intensity of shear at neutral axis = 134 lbs. per sq. in.

No. 29.—Spruce Joist, 4 in. by 12⅛ in. Span 18 feet. Loaded at center.

Tested by Messrs. Scott and Foran.

Load in lbs.	Deflection in inches.	Differences.	
485	.0000		
887	.1048	.1048	
1,289	.2169	.1121	
1,691	.3267	.1098	
2,093	.4424	.1157	
2,495	.5488	.1064	
2,696	.6227	.0739	
2,897	.6768	.0541	
6,917	.....	.....	Slight cracks heard.
8,324	.....	.....	Breaking load.

Modulus of rupture = 4,586 lbs. per square inch.
Mean deflection for 402 lbs. = .1128.
Modulus of elasticity = 1,259,224 lbs. per square inch.
Maximum intensity of shear at neutral axis = 129 lbs. per sq. in

No. 31.—Spruce Joist, $3\frac{1}{8}$ in. by 12 in. Span 18 feet. Loaded at center.

Tested by Messrs. Davis and Morse.

Load in lbs.	Deflection in inches.	Differences.	
845	.0000		
887	.1486	.1486	
1,289	.3030	.1544	
1,691	.4514	.1484	
2,093	.6129	.1615	
2,495	.7615	.1486	
3,701	.....	.....	Cracking commenced.
7,721	.....	.....	Breaking load. Broke suddenly by compression of top fibers and shearing along the neutral axis. Split showed several small pin knots, running vertically in the beam, and apparently pinning the sides of the fracture together.

Modulus of rupture = 5,559 lbs. per square inch.

Mean deflection for 402 lbs. = .1523.

Modulus of elasticity = 1,231,498 lbs. per square inch.

Maximum intensity of shear at neutral axis = 154 lbs. per square inch.

DISCUSSION.

Mr. Partridge.—I would like to ask Professor Lanza whether he has made anything more than judgments of the quality of the timber by the eye—whether he has made any microscopic examinations or attempted to carry his work further than the unassisted eye would carry it.

Professor Lanza.—I have not, Mr. President. Mr. Partridge's question gives me an opportunity to say something I would not wish to state in the paper formally. That is, that I amused myself by guessing—and the students have done the same thing to some extent—at what the pieces broken this year would bear, judging simply by the eye. I will give an idea of some of those pieces. Take the first one, No. 19, I think the guess was 4,575; the break-

ing weight is 4,404. For the second one, I think, our guess was 5,500; the breaking weight is 5,815. On No. 22, the guess was 12,000, which shows that the general appearance of the timber will enable us to approximate its breaking strength. It broke at 12,500.

Mr. Partridge.—I have had some little experience in what might be called the investigation of the character of a piece of timber microscopically. As most mechanics here know, perhaps one of the earliest uses of the microscope was in the investigation of the character of different woods. The first specimens that I mounted opened the structure of a piece of wood so that you could characterize it with almost the distinctness with which we characterize a piece of brickwork. We know whether it is fine brickwork or brickwork of the commonest kind. We know whether the joints are half-inch or as thin as they can be got. So in a piece of timber, nature's building becomes very plain under a power of perhaps 150, 200 or 300 diameters, just as may be convenient. The cells open themselves out. The character of those cells, whether they are well united to each other or far apart, the relationship of the sap pores to the general mass of the timber and the character of the binding—that is, the medullary rays—become very clear; so that I think by micrometric measurements of the photographs—for I would not attempt any work of this kind without photographing every specimen to go under the microscope—that it would be easy to know the reasons for a great many things which at the present time are obscure. I presume if the Professor should mount sections from those timbers which break in so peculiar a way, that he would find characteristics of structure visible which would account for that particular manner of breakage. And I have found, certainly, in yellow pine, cases where the structure exhibited so marked a difference in a good piece of timber and a poor piece, that one would have no hesitation in assigning the cause of breakage. Unfortunately my photographs and negatives are in Philadelphia. They were recently exhibited there by Dr. Grimshaw. If they were here, I could make use of the lantern and show definitely what I mean. Not long ago a bridge was erected near this city in which two **A** frames carried the load of a draw. The **A** frames, owing to the diminished size of the bearing casting, overhung the casting on which the draw rested by about 12 inches. The timbers themselves were two 12-inch timbers, one above the other. When an empty truck was passing the **A** frames gave way, and the foot of one of the frames was pulled down through

that 24 inches of timber, shearing it off almost like a knife. Pieces came out nearly egg-shaped. One of those was given me, and on mounting the section for the microscope, I found that it was not unlike the appearance of a brick wall where there is more mortar than brick. The cells were long, large, continuous and very slightly joining, and the medullary rays, when a section parallel to the bark was taken, appeared only at long intervals.

A good piece of pine showed the medullary rays scattered up and down so thickly that instead of having vertical lines with here and there a bunch on them, you had a series of small bubbles, as it were, strung along the line representing the vertical fiber. Such differences as that were so marked and in connection with tests of strength would give such clear indications, that it seems to me very unfortunate not to have the microscopic work hand in hand with the testing. It is, I think, to timber what chemical analysis is to the testing of metals.

Professor Eglestón.—I regret that I did not hear the paper, nor more than the last sentence of the discussion. I had occasion some years ago to draw up the programme of a report for the United States engineers with regard to the testing of metals used in the fortifications of the United States. I have had occasion once or twice in the engineering societies to allude to this fact, and have often had cause to regret, in making researches in my laboratory on metals, as I regret now in public, that no report of these experiments was ever made, and no report of the subsequent investigations exists except, perhaps, in manuscript in some pigeon-hole in Washington. In making the report to the Board of Engineers I told them then that any experiments that were made in testing metals would hardly be a fair exhibit of those tests unless a microscopic examination accompanied them. In one of the last numbers of "Eisen und Stahl," perhaps the best publication on iron and steel that is being issued in Europe at the present time, I find a long article insisting upon microscopic examinations accompanying the tests of metals. They refer there particularly to iron and steel. In the course of my professional experience, in the last eighteen months I have had occasion to use the microscope a great deal in this way, and I have recently determined that the next expenditure that I have occasion to make on such investigations, must be made in the direction of specially adapting a microscope for the study of tests of metals. I do not think there is a more important branch of testing than this kind of examination. There is a change, which

may require several hundred examinations to be made before many conclusions can be drawn, which goes on in every metal or alloy that I have ever examined, which is often made visible to the eye in the course of the commencement of the fracture, and afterward in the fracture itself, but which can only be completely studied under the microscope. But I think it is evident to any one who would make any examination of the subject at all that there is here a method of investigation which, although it cannot be said to be entirely new, may give as valuable, or even more valuable, results as the testing machine itself. I believe that similar changes may be detected in woods, and I therefore feel the greatest interest in any new investigation of structural materials.

Professor Lanza.—I fully believe in the value of the suggestions made. There are, however, several other points that ought to be investigated, one of which is the action of time upon the breaking weight. The first beam that was tested last year was a 2 x 12. I have forgotten the span, but I remember that the load was brought to about 5,800 pounds. It had to be left over night. The load dropped off, as it will, of course, in any screw machine, to about 3,000, and the next day it broke at 3,500. It had been under load over night. I have no doubt at all that the modulus of rupture will be very much lowered from those figures as soon as the action of time is taken into account. So also will be the modulus of elasticity, especially in wood. The deflection keeps increasing for a long time. The object of the tests has been to enable us to say with some degree of certainty, when we have a piece of timber to use, what will be approximately its breaking weight and what its modulus of elasticity. Then we can see what effect a time test will have, whether half its breaking weight or a quarter, or what part of its breaking weight will break it in the course of time. But, until we had some such data with which to start, it seemed almost useless to experiment on any more recondite matters.

Mr. Charles E. Emery.—I will take but a moment on this subject. It seems difficult to understand at once why a beam, flexed when the load is applied at the top, should divide only at the neutral axis. It is, however, in keeping with what I may call a theory advanced in a paper written about two years ago by myself in explanation of the high results given by beams as compared with those worked out by the usual formula. It will be recollected by those who saw the paper, though probably not many here present did, that the explanation was based on the calculated position of the

isodynamic curves in the longitudinal section of a beam. They curve from both upper and lower edges of the beam at either side of the load through the central section, and out again the other side. If we consider, as is usual, that at the neutral axis there is no motion, and at the outside maximum motion, my theory only requires that the beam bend a little at each side of the load, where, the strain being less, there could be an additional strain thrown on the fibers near the neutral axis along the general line of the corresponding isodynamic curve. If this be true, it seems very probable that there is a whole bundle of fibers, above the n utral axis, pulling with a greater intensity toward the axis *than is due to their position*, so that there is a shearing force, longitudinally, tending to produce rupture at the axis; and the additional strains on fibers near the axis relieve the outer fibers, thus accounting for the discrepancies between the practical results and those shown by the usual formula. As a matter of course, we can see why there is a tendency to produce shearing when the load is applied to the bottom of the beam, but this explanation applies when the load is applied either to the top or bottom.

Professor Lanza.—I should like to say that the formula from the ordinary theory of beams for the intensity of the shearing force at the neutral axis is in the case of rectangular beams very simple, especially in the case of a rectangular beam loaded at the middle. It is simply the supporting force divided by two-thirds of the area of the cross-section. That gives for that best beam, No. 22 (referring to the table), a shearing force of 202 pounds to the square inch at that neutral layer. The other beam that broke in that way gave 190. Those shearing forces are below the shearing forces that were determined at the Watertown Arsenal for the shearing strength of spruce. Nevertheless, of course the shearing of the beam occurs at the weakest part. But I have not yet seen enough consecutive evidence in the experiments figured up to enable me to make a connected theory.

ADJUSTABLE CUT-OFF FOR MARINE ENGINES.

BY

H. S. HAYWARD, JERSEY CITY, N. J.

As a practical engineer on ocean steamers, I have experienced a great deal of economy, especially where we have had a limited coal supply, in the judicious use of an adjustable cut-off. There are times when the engineers can avail themselves of favorable winds and smooth seas, and at other times they require all the power that their engines will develop.

In my railroad experience I find that a great deal of economy has also been realized on our locomotives by encouraging engineers to carry their steam up to the highest point allowed them, and cutting off their engines shorter instead of using the throttle.

Fig 2.

That, however, is a different case from the one we have under consideration, but it still demonstrates that engineers, whether on land or sea, can economize by cutting off shorter on the stroke of the engine instead of throttling the steam as it enters the cylinder.

Now, the advantage that we get by the use of the adjustable cut-off on the ferry-boats is on our long run up-town where we go up with the tide and come down against it, or *vice versa*.

These ferry-boats are required to make schedule time in order to connect with the trains; and to work our boats efficiently, I have adopted this system of a simple adjustable cut-off.

This cut-off attachment consists of a light rod running between the two steam-lifters, and on each end of the rod are plates with a rectangular slot, as shown in Fig. 2, at *ff*.

The upper and lower steam-lifting arms contain the mechanism for dropping the valves.

This consists of a plain bolt operated by a yoke and cam movement, as shown in Fig. 3.

These arms are cored in casting so that all they require in fit-

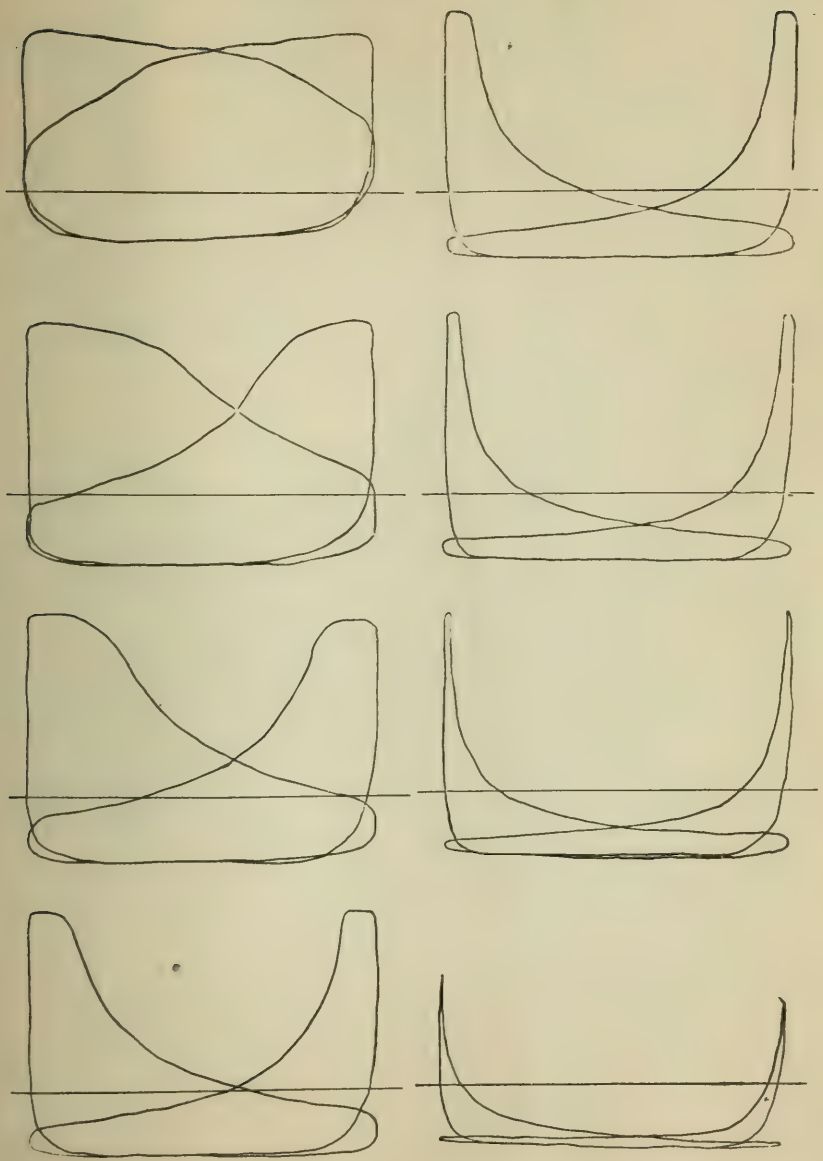


Fig. 3.

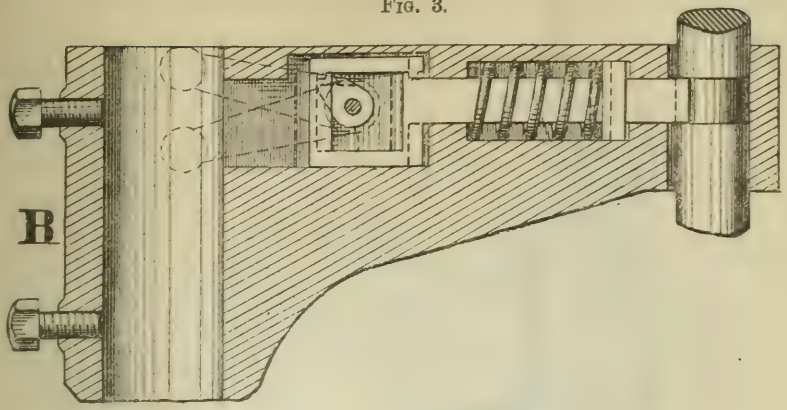
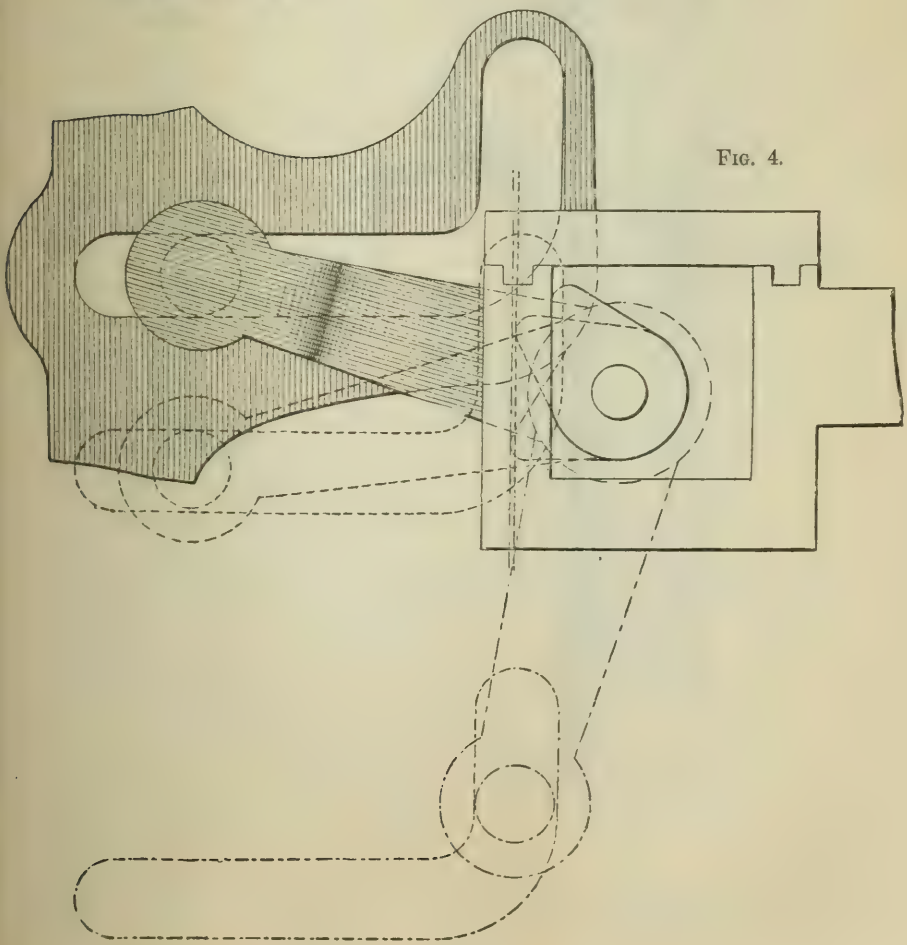


Fig. 4.



ting the bolts is a straight cut through them, and the fitting of the top plate.

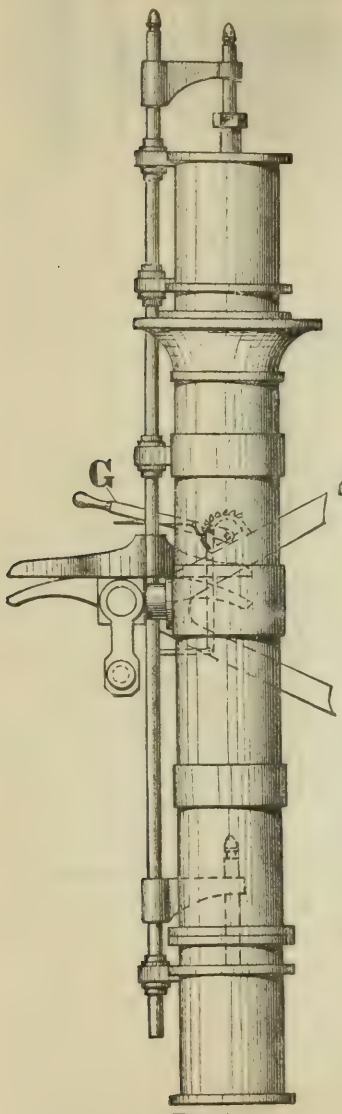
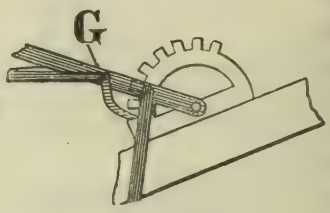


Fig. 1.

The bolt is operated by a cam which works in a square yoke, and that cam is connected with a lever having one end operated by the pin working in the rectangular slot, as shown in Fig. 4.

The raising and lowering of the rod having the terminal plates with rectangular slots causes the variations in points of cut-off by releasing the valve-stem from the brackets on the lifter rods at different points, as shown by the accompanying indicator cards.



The handle, *G*, as per Fig. 1, for operating this cut-off, is attached to the center bracket of the rock shaft. When this is thrown up in the first notch of the quadrant, the rod with rectangular slots is raised, so that when the valves are lifted to the full height the cam does not come in contact with the yoke, and the engine is working by what is known as the Stevens cut-off—the valves being raised and lowered by the steam toes and wipers.

With the use of this attachment you will notice, according to the indicator cards, that we have a very wide scope for variations.

If we have a valve set to close at three-quarters of the stroke, we can vary the point of cut-off down to a few inches on the length of stroke, or throw the steam valve stems entirely out of gear, allowing the engine to work on the vacuum.

I do not think that any further description is necessary; but I should be very much pleased if any members taking an interest in this subject should avail themselves of the opportunity when they are crossing to Jersey City, to examine the new ferry-boat "Baltimore," where it is now in operation.

I also beg leave to call your attention to a simple form of dash-pot which is used in connection with this cut-off (Fig. 5).

This dash-pot consists of two chambers—the inner one being made of brass, allowing a space between the outer and inner chambers little more than equal to the capacity of the inner one—the opening between the two chambers being made in the bottom of the inner brass chamber.

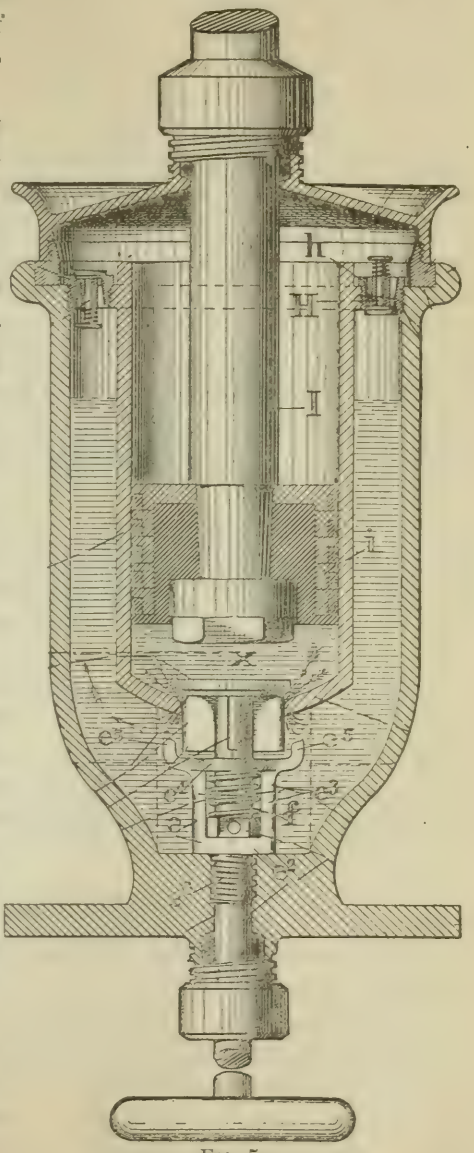


FIG. 5.

The main valve stem passing through the bottom of the steam chest, is carried down a sufficient length according to the location of the dash-pot, and is fitted with a solid plunger, with cast-iron packing-rings which work up and down in the inner brass chamber of

the dash-pot as per sketch. When the main steam valve of the engine is raised, since the lower end of the valve stem is connected with this plunger, it is also raised, and that produces a vacuum in the lower part of the inner dash-pot chamber. The valve, *a*, between the outer and inner chamber, is raised by the vacuum thus produced, and by the flow of oil from the outer to the inner chamber.

This valve is to a certain extent self-operating, on account of the compression of the spring working in the yoke connected with a regulating valve stem in bottom of dash-pot.

This regulating valve stem is used in adjusting the minimum opening of the foot-valve, so that on the return of the plunger, when the main valve is dropped, there is increased resistance to the passage of the oil on its return to the outer chamber on account of the partial closing of the valve. It is held but a short distance from its seat by the regulating valve stem.

There are also relief valves placed at the upper part of the dash-pot between the inner and outer chambers, as shown on sketch.

These prevent the main valve from being held from its seat on account of there being an excess of oil in the outer chamber, and the ingress valves are so arranged that if there should be any excessive leakage of oil through the plunger packing, the oil on the top of the plunger would be allowed to flow back into the outer chamber, and not cause an undue strain on the top cover of the dash-pot.

This practically makes it as nearly as possible a self-regulating dash-pot.

In order to seat the main valves slowly or rapidly, it is only requisite to increase or decrease the fixed amount of opening of the cataract valve between the two chambers, which is done by the regulating valve stem.

DISCUSSION.

The President.—I think Mr. Hayward has been making some experiments on that boat?

Mr. Hayward.—I have not been making any experiments. We are running her at present on what engineers term the third notch; that is but two notches below the point at which the valves are set. We still have two notches to go on for bad weather and ice in the river. That is a very important point, especially on the longer routes.

The President.—Haven't you been using that engine at very small points of cut-off, and very high rates of expansion?

Mr. Hayward.—The cut-off is so adjusted that you can use it in the place of a throttle. The engineer can slow down coming into the slip, and when he unhooks her, he throws the lever up, the same as he would upon his throttle, and then he is prepared to work his engine by hand.

The President.—How does your wheel behave on a short cut-off?

Mr. Hayward.—We turn a very even wheel. But in connection with this I would state that we have constructed the outer ring of our wheel very much thicker than heretofore, and the boat is more free from the vibrations which you find on ferry-boats.

Mr. Holloway.—I would like to ask the gentleman whether it is the practice to cut off on the descending or ascending stroke?

Mr. Hayward.—The descending.

Mr. Holloway.—How do you manage to cut off at half-stroke?

Mr. Hayward.—You have to have your engine set for a very high lift, and to follow the greater portion of your stroke, so that you have from that point to any point under left to cut off at. They all have to cut off on the lift.

Mr. Holloway.—I think it is an excellent thing, but it is very similar to what has been used on the Lakes for several years.

Mr. Hayward.—All I look at in this is its simplicity and economy of construction.

THE PROTECTIVE VALUE OF BOILER INSPECTION.

BY

F. B. ALLEN, HARTFORD, CONN.

From a paper read by Mr. E. B. Martin, before the Institution of Mechanical Engineers at Manchester, England, in 1866, we learn that a very disastrous boiler explosion occurred in London in the year 1815. That explosion and others that occurred subsequently were made the subject of an inquiry by a Parliamentary Committee in 1817, who recommended, among other things, "that boilers should be made of wrought iron instead of cast iron or copper, which had been the materials mainly used previously; that they should be inspected and tested; and that there should be two safety-valves, each loaded to one-third of the test pressure under penalties for any excess."

Until 1830, boilers were rarely worked above ten pounds per square inch; indeed, seven pounds was the ordinary pressure. After that period the principle of working high-pressure steam expansively came into use; the pressures were increased to thirty and forty pounds per square inch, without increasing the strength of the weak forms of boilers then used, and in consequence many violent boiler explosions occurred, directing public attention to the subject, and the necessity for a better system of protection from the occurrence of these sad disasters. Sir William Fairbairn, who had for some years previously interested himself in this matter of boiler explosions, rendered invaluable service to the authorities where inquests were held (indeed, Sir William seems to have been the pioneer of the much-abused mechanical expert of our day), and organized in the city of Manchester an association of manufacturers and mill-owners for the protection of the lives and property of those who were exposed to the dangers of boiler explosions. The association established a system of periodical examinations and inspections, and employed skillful inspectors to have supervision over all boilers operated by its members. The plan worked admirably, not only in the prevention of boiler explosions, but the advice and recommendations made by its inspectors effected an increased

economy in the generation of steam, with greater durability of the boilers.

This association has since attained a world-wide celebrity, and the contributions of its present Chief Engineer, Mr. Lavington E. Fletcher, in the department of boiler engineering, have been important and valuable.

In a communication by the writer to the AMERICAN MACHINIST, November, 1878, comparing the protective value of the Government test of steamboat boilers under the direction of the board of United States Supervising Inspectors, with that of a more thorough and systematic examination by a boiler inspection and insurance company, compiled from official records in both cases and extending over a period of six years, it was shown that the cost in losses by explosion for each boiler inspected by the Government was $13.76, while that of the insurance inspection cost per boiler in losses paid $1.18. It will be apparent that the loss reported by the boiler insurance company was only that for which they were liable, and did not represent the entire loss in cases where the amount insured was less than the real value of the property. Assuming that the insurance policy covered but 25 per cent. of the total loss—and this assumption is undoubtedly greatly in excess of the actual amount—we have the cost in losses per boiler, inspected by the insurance company, at $4.72. Expressed in protective efficiency, the U. S. inspection was to that of the insurance inspection as .343 to 1. In comparing the advantages and disadvantages of the two systems, it will be conceded that the insurance inspection was chiefly that of stationary boilers, whose surroundings are ordinarily superior to those of a marine boiler, while in construction and attendance they are inferior to it.

Mr. Henry Hillier, Chief Engineer of the National Boiler Insurance Co., of England, testified before the "Parliamentary Select Committee on Steam Boiler Explosions," London, 1870:

"The explosions reported to me during the five years ending 31st Dec., 1869, were 288; of these I have obtained reliable particulars of 223, due to the following causes:

"*First.*—80, or 36 per cent., due to defects of construction, either of material or workmanship.

"*Second.*—87, or 39 per cent., due to defects arising during ordinary use of the boilers, such as corrosion, fractures, and grooving.

"*Third.*—56, or 25 per cent., due to actual neglect of attendants, as deficiency of water and, in most cases, over-pressure.

"Particulars of the remaining 65 explosions were not obtained."

Seventy-five per cent. of the defects enumerated above, comprising the first and second predisposing causes of explosion, are those which it is the special province of boiler inspection to discover, either at the first or subsequent examinations; while the system of quarterly visits of inspection made to the boilers while under steam in ordinary use, to examine safety-valves, steam-gauges, and other safety appliances, with its attendant supervision over those in charge of the boilers at the time of the inspector's visit, reduces to a minimum the danger to be apprehended from the third, or remaining cause.

I quote from the annual report of the inspection department of the Hartford Steam Boiler Inspection and Insurance Co., as follows:

SUMMARY OF THE INSPECTORS' REPORT FOR THE YEAR 1881.

During the year 1881, there were made 22,412 visits of inspection, being an increase of 1,473 over the number made in 1880; the number of boilers inspected was 47,245, an increase of 2,079 over the number inspected the previous year, while the number of complete internal inspections foots up 17,590, an increase of 1,580 over the number made in 1880. The hydrostatic test was applied in 4,286 cases, the majority of which were new boilers. This is an increase of 796 over the business of the preceding year.

The total number of defects found which were considered serious enough to be reported was 21,110, of which number 5,801 were of a dangerous nature. This does not include many defects of a less serious character.

The following table shows the defects in detail:

Nature of Defects.	Whole No.	Dangerous.
Furnaces out of shape	1,164	301
Fractures	2,417	1,414
Burned plates	1,180	426
Blistered plates	3,260	468
Cases of deposit of sediment	2,752	532
Cases of incrustation and scale	4,082	494
Cases of external corrosion	1,346	450
Cases of internal corrosion	899	266
Cases of internal grooving	225	128
Water-gauges defective	401	157
Blow-out defective	255	132
	17,981	4,768

Nature of Defects.	Whole No.	Dangerous.
Defects brought forward	17,981	4,768
Safety-valves overloaded	296	169
Pressure-gauges defective	1,647	375
Boilers without gauges	552	51
Cases of deficiency of water	128	101
Braces and stays broken	478	313
Seams leaking	8	3
Defective heads	13	13
Loose tubes	4	
Mud-drums defective	3	3
Dangerous defects unclassified		5
Total defects	21,110	5,801
Boilers condemned		363
Heads condemned		13
Mud-drums condemned		3

We would call attention to the above record of defects discovered, and then most respectfully ask: Is not the periodical inspection of steam boilers of some slight value? There can be but one answer to the above question, and that must be in the affirmative. It is impossible that a system of inspection which brings to light a total of nearly *six thousand* dangerous defects in one year, can fail of accomplishing an incalculable service to the steam-users of this country.—(*The Locomotive*, N. S., Vol. 3, No. 2.)

Many of the improvements in the construction and material of shell boilers in this country, during the past fifteen years, are due to boiler inspection and its demands for better work, in accordance with the requirements of its standard. A brief review of the principal or more important of these improvements may not be inappropriate in this paper.

Most of us remember the stationary steam boiler of twenty years ago, where the aim of the boiler-maker was to place as many small tubes in the boiler as it was possible to do, the value of circulation not being understood or appreciated. Contrast this with the tubular boiler of to-day, with its tubes set in vertical rows, no tube approaching nearer than three inches to the shell, with a clear opening down the middle of from two to six inches, according to circumstances, for a solid body of water, giving better circulation, affording better facilities for cleaning the boiler, as well as for making repairs to the fire sheets when required.

All shops were provided at that time with those mysterious tools known as drift pins, although no boiler-maker ever countenanced

their use. As an indication of progress, we may congratulate ourselves that evidences of their use are not nearly so common as they were a few years ago.

The advent of machine riveting required a more careful system of laying out and punching rivet holes, to insure satisfactory work in the completed boiler, the drawing of a rivet-head in any required direction, to cover an irregular-shaped hole, being much easier of accomplishment by hand riveting than with the machine. In the matter of calking riveted joints there has been a marked improvement over the carelessness that formerly prevailed under the old method, with the certainty of its breaking the skin of the iron in the under plate. It is wonderful how tenaciously many of our boiler-makers yet cling to that old relic of barbarism, the plane-faced calking tool.

The common practice in boiler construction, until recently, was to cut out the shell of the boiler the full size of the dome opening. Many serious explosions have been traced to weaknesses of that kind. In some other cases the appearance of leaks around the base of the dome, that continued to leak after repeated calking, led to an investigation of the cause, and a relief by bracing which prevented the distortion of the weak part around the dome flange. Occasionally new boilers are found defective in this important particular.

The problem of properly supporting long boilers, that, so far as practicable, there may be an even distribution of the load, is one in which there has been some diversity of opinion among engineers and boiler constructors, as to the best location of the supports to accomplish the object. The need of graduated supports on a boiler thirty feet long ought to be apparent to every one, yet inspectors often find boilers of this description with their whole weight resting on their extreme ends (front and rear), the effect of which is to throw an undue strain on the middle girth seams, which, if not discovered in time, and remedied, will cause a seam rip and the projection of the halves of the boiler in opposite directions, with a terrible destruction. The violent explosion at the Allentown Rolling Mill, in January, 1881, by which 13 persons lost their lives, was caused by a defect of this kind. It was estimated in that case that the weight of the boiler structure and its contained water was about 12,000 pounds.

In boiler fittings, the regulations of the United States Steamboat Inspection Service, as well as the inspection and insurance com-

panies at home and abroad, require a proper safety-valve for each boiler. In stationary boilers it should be attached by a nozzle, or some such suitable connection, directly to the shell of the boiler, without intervening stop-valves.

The practice of having but one safety-valve for a battery of from two to five boilers is a murderous one, which has been the cause of some of the most disastrous explosions known in this country. This matter deserves the attention of the authorities, and laws should be enacted in the different States, making the further use of boilers connected in this manner unlawful, and punishable by suitable penalties. In closing this retrospect, special credit is due Mr. J. M. Allen, President of the Hartford Steam Boiler Inspection and Insurance Company, for important investigations and the dissemination of much useful information, notably upon the subjects of the "Holding Power of Boiler Tubes," "Strongest Forms of Riveted Joints," and "Plan for Supporting Long Boilers in Iron Works."

The plan of condemning steam boilers after a prescribed term of years has been advocated, but apparently finds little favor with either engineers, boiler-makers, or boiler-users. All agree there is a time when a boiler reaches the limits of its usefulness, and should be relegated to the scrap heap: viz., when its condition indicates that it requires that treatment.

The practice of casting away passenger-car axles after a certain mileage, no matter what their apparent condition may be, is now generally adopted by our leading railway managers. This has been cited as one worthy of imitation in limiting the life of a boiler. Desirous of learning the practice of the Pennsylvania Railroad, and whether they had abandoned the one commonly used by engineers of determining the question of condition by an inspection, substituting in its stead the uncertain limitation of age irrespective of condition, I wrote for information to a gentleman who holds a responsible position in its machinery department. He replied as follows: "* * * Now, in regard to the life of a boiler, we do not pretend to place any limit upon their age; all depends upon their general condition, knowledge of which is obtained from weekly inspections or examinations of stay-bolts and fire-box sheets, and internal examination at intervals. So you see we are mortal like yourselves, and depend upon good material, mechanical skill in construction, and watchful care after they have been put in service for prolonging the existence of boilers."

The protective value of boiler inspection is further demonstrated by the following statement of the Manchester Steam Users' Association: "During the past fourteen years the Association has issued upward of 30,000 boiler guarantees, and not a single person has been killed or injured by any guaranteed boiler."—(*Engineering*, Vol. 27, p. 258.)

It is understood that the guarantees of this Association are issued only on selected boilers, located within a comparatively small territory, thereby enabling its inspectors to have constant supervision over them. These conditions do not exist in this country, except in our large cities. The Metropolitan district of the Hartford Steam Boiler Insurance Company comprises the cities of New York, Brooklyn, and Jersey City; in this district from 1866 to 1882, covering a period of sixteen years, but one explosion has occurred from which death or injury resulted.

During the year 1881, the company issued policies on some 15,000 boilers throughout the country, but two of which exploded. When the fact is taken into consideration that many of its policies are on boilers in sparsely settled parts of the country, run without skilled attendance, in many cases using bad water, and subject to many other unfavorable conditions, this showing is indeed remarkable testimony for the protective value of boiler inspection.

The proud record of the Manchester Company, the pioneer inspection company of the world, is undoubtedly due, among other causes, to the hearty co-operation of its members in the work of periodical inspection, and a prompt acquiescence in its recommendations. The importance of the subject of boiler inspection in its relation to the protection of human life appeals to every steam-user in the land to obtain the most thorough system of inspection offered, and to make suitable arrangements for periodical examinations.

Boilers should be permitted to remain long enough out of service to cool properly, and permit a thorough examination of their setting and fitting. It is now no uncommon occurrence for an inspector to have his shoes destroyed by hot cinders and ashes, or his flesh burned in an endeavor to make an examination of boilers and settings which he has been notified are ready for inspection. Such an inspection can be one only in name, and, obviously that kind of co-operation on the part of the steam-user in preparing for his inspection is not the kind advocated in this paper, nor will it afford the full measure of protection here contemplated.

The greatest need of the boiler inspection service in this country to-day is hearty and intelligent co-operation on the part of the steam-user, by which its efficiency may be further increased.

DISCUSSION.

Mr. Le Van.—I would like to ask Mr. Allen if I understood him to say it was proper to cut out the full size of the drum from the boiler shell?

Mr. Allen.—It is not proper.

Mr. Le Van.—Of what benefit is the remaining part of the boiler covered by the dome?

Mr. Allen.—It gives increased strength by imparting stiffness to the structure. The plan that I have advocated for boiler domes has been to place the manhole plate on the shell of the boiler. The statement made in my paper has special reference to boilers having the manhole on the top of the dome. The better plan would be to place the manhole on the shell of the boiler, and where a dome is used, to perforate only the plate.

Mr. Le Van.—What does the gentleman gain by that? It is nothing more than a bent stay.

Mr. Allen.—There is a certain stiffness gained. I do not mean to contend that the difference is very great, but the practice of cutting out a large amount equal to the full size of the dome is reprehensible.

Mr. Le Van.—Does not the gentleman know that the pressure is the same on each side?

Mr. Allen.—Yes, sir.

Mr. Le Van.—Then how can it be of any strength to the boiler?

Mr. Allen.—By imparting a stiffness which is necessary to prevent distortion.

BACK PRESSURE ON VALVES:

OR, THE EQUILIBRIUM LINE BY EXPERIMENT AND THEORY FOR BROAD-SEATED VALVES.

BY

S. W. ROBINSON,

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THE title of this paper perhaps poorly indicates its true import. More specifically, an attempt is made to determine by experiment what fractional part of that pressure exerted upon the top surface of a valve by a fluid is required, when acting from below, to raise that valve from its seat. The valve is supposed to have a broad surface of contact with its seat, as in the case of a slide valve in the steam chest of an engine where the flanges have a broad lap.

Every designer of steam engines with slide valves finds the question asked of himself, "What force is necessary to slide the valve on its seat?" The first showing of an answer may be, "It depends on the pressure and the coefficient of friction." Probably but little is positively known about either the *effective* pressure, or the coefficient of friction in this case. The present object is to throw light upon the question of effective pressure.

To illustrate, suppose a common D slide valve has a surface contact with its seat of $12'' \times 12''$ outside, less a $5'' \times 10''$ D cavity inside as shown in Fig. 1, the cavity being supposed in communication with the exhaust. It seems evident that the effective pressure is not $p_1 \times 12 \times 12 = 144 p_1$ where p_1 is the pressure in pounds per square inch, because why may it not be merely the $p_1 \times 5 \times 10 = 50\ p_1$ as due to the cavity itself? The most thoughtful probably will assume some area between the inside and outside, in the neighborhood of that inclosed by the dotted line, by which to multiply p_1 for the effective pressure. This line I hereafter in this paper call the "*equilibrium line*," and the area inclosed within it the "*equilibrium area*," because the pressure p_1 multiplied by it, equals a force which, acting from below, will just lift the valve from its seat.

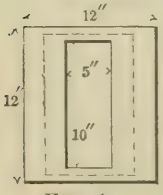


FIG. 1.

When the equilibrium area falls between that of the cavity and of the outside of the valve, it appears that the fluid pressing upon the top of the valve creeps under the edges to some extent, and that the film of fluid under the valve near the cavity relieves itself by escape into the cavity. It would seem from this reasoning—required for explaining the equilibrium line,—that for true surfaces a film of almost infinitesimal thinness is constantly creeping along between the "contact" surfaces, toward the cavity; and that on this route, the pressure of the creeping fluid is continually falling, starting with nearly that of the higher pressure side of the valve, and ending at the cavity with the pressure of the latter.

When the whole lifting pressure exerted by the creeping fluid between surfaces is known, the equilibrium line can be located. The theoretical determination of this lifting action is the same as that for finding the force tending to throw a packing ring from its seat. Formulas for the latter are given in the published transactions of this Society, Vol. II., pp. 27 and following, in my paper on *A Rational System of Piston Packing*. According to that paper it appears that for a rectangular valve like Fig. 1, and for an incompressible fluid, the pressure falls on a straight line declivity, from p to p_2; p being the pressure just at entry, and p_2 that within the cavity. The fall from p_1 to p is due to the acceleration for entry into the space. The latter, it is shown in the paper cited, will be a small fraction of the whole, and it will be neglected here.

In Fig. 2 let the shaded area stand for a section through a *D* slide valve like Fig. 1, the square outlines being best for the present purpose.

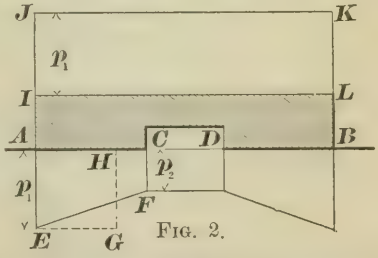


Fig. 2.

If p_1 be the absolute pressure on the top of the valve, and p_2 the absolute back pressure in the cavity; then according to what is said above, EF will represent the line of falling pressure from p_1 to p_2. Also it is evident that if the area $IJKL$ stands for the total absolute downward pressure upon the top of the valve, then the area $AEFC$ will represent the total absolute lifting pressure at one side of the valve, due to the creeping fluid along AC, and tending to raise the valve from its seat. Now draw EG parallel to AC, and make the area $AEGH = AEFC$, then the lifting pressure of the creeping fluid neutralizes so much of the top pressure $IJKL$ as lies directly over the length

AH. Hence H is the position of the equilibrium line. Likewise we may find the point on BD.

From the figure, it appears that AH will equal a half AC only when $p_2 = 0$.

As an example, suppose $p_1 = 60$, $p_2 = 15$. Then the mean pressure on AC is

$$P = \frac{p_1 + p_2}{2} = 37.5$$

and

$$P \times AC = p_1 \, AH,$$

or,

$$AH = AC \frac{P}{p_1} = AC \frac{37.5}{60} = AC \, .625.$$

Hence the equilibrium line is nearer C than A. More specifically, it appears that 62½ per cent. of the pressure upon that part of the top of the valve which lies above AC and BD is counteracted by the lifting action of the creeping fluid.

This supposes the fluid incompressible like water (nearly so). Hence the above calculation is suited to the case of a valve working in water. For quite a range of pressure under this case, we may quote from the paper on piston packing referred to,

TABLE A.

$\frac{p_1}{p_2}$ =	$\frac{P}{p_2}$ =	$\frac{P}{p_1}$ =
2	1.5	.75
4	2.5	.625
6	3.5	.583
8	4.5	.562
10	5.5	.55

where p_1 is the absolute pressure upon the top of the valve, p_2 the absolute back pressure, and P the mean pressure due to the creeping fluid. Then

$$AH = AC \frac{P}{p_1}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

thus locating the equilibrium line.

If the fluid is elastic like air, and the flow in the space AC is adiabatic, we have from the same source,

TABLE B.

$\frac{p_1}{p_2}$ =	$\frac{P}{p_2}$ =	$\frac{P}{p_1}$ =
4	2.72	.68
6	3.94	.657
8	5.18	.647
10	6.42	.642

and for the isothermal flow of elastic fluids,

TABLE C.

$\frac{p_1}{p_2}$ =	$\frac{P}{p_2}$ =	$\frac{P}{p_1}$ =
4	2.80	.70
6	4.09	.682
8	5.41	.676
10	6.73	.673

These tables differ but little, and values may be selected to suit any case in hand, including even a condensable fluid like steam, because, whether steam, or water due to condensation, fills the space AC, the case will fall within the tables above. If any exception is to be made on the supposition that with steam the percentage of water will increase on the route from A to C, it will be to the effect that the lifting force is greater than the calculation would give, and hence on the safe side.

To illustrate further the use of the above tables and formula, suppose a D slide valve in a steam or air chest is 10 inches over all, and with a D cavity of 4 inches. Each flange will then be 3 inches if equal one to the other. Further, take

$$p_1 = 90\,;\ p_2 = 15.$$

Then

$$\frac{p_1}{p_2} = 6\,;\quad \begin{aligned} AH &= AC\ .682 \text{ or } AC\ .583 \\ &= 2.05 \text{ inches or } 1.75 \text{ inches,} \end{aligned}$$

if the last table be selected, or the first respectively.

Hence, doubling the values, we get for both flanges outside the equilibrium line

4.1 or 3.5 inches respectively,

or within the equilibrium line

5.9 or 6.5 inches respectively.

Hence the effective pressure of the valve upon its seat is as though the last named widths of equilibrium area only were subject to the pressure p_1.

The Equilibrium Line by Experiment.

In the spring of 1881, Student J. H. McEwen subjected this question of back pressure to experiment in my Mechanical Laboratory, as a practical problem in course. The appliance explained below was made by him for the purpose. In experimenting, the data were procured partly by Mr. McEwen and partly by Mr. C. F. Marvin. The results obtained from reducing the data to the valve, are given in plate I., p. 164.

The appliance employed is shown in section in Fig. 3, in which *A* represents the valve, *B* its seat, *D* the bed plate of the containing chest, *C* an inverted hollow piece, which, when bolted to *D*, together constituted the chest; *G* a nozzle for admitting the fluid pressure, *H* a cock for draining the chest, *E* a lever which, by means of a strut reaching up through the seat, will lift the valve *A*, and *F*, the scale pan for loading the lever.

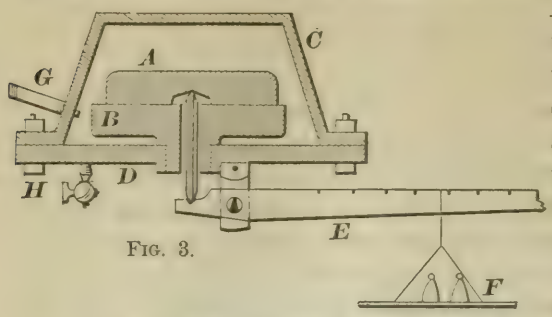


FIG. 3.

The valve and seat are circular in plan, and not rectangular. They were carefully fitted together by facing truly in a lathe, and then by grinding with emery. The grinding was done partly in the lathe and partly by hand with cross motion. It is perhaps to be regretted that this fitting was not done by scraping, but as they were, the surfaces possessed the properties of surface plates in high degree. Placing *A* upon *B* with clean joints, the former would float upon the latter for five or ten seconds, lubricated by air. When settled, *A* would lift *B*, and support it for a considerable time. The surfaces were mirror-like for smoothness throughout. Though the job was well done for grinding with emery flour, yet it is believed that a somewhat more satisfactory contact could have been obtained by the scraper. The outside diameter of the valve *A* is six inches, and its cavity two and a tenth inches. The seat *B* was about three-fourths of an inch larger than *A* outside, with a central aperture of about one inch. This excess of surface on *B* was intended for insuring contact on the entire lower surface of *A*, even should it get eccentric with *B*. The seat *B* was mostly free from the bed plate so as to relieve it from the strains and flexure of the latter. A neck projecting down from *B* was pressed into the bed, *D*, with a free space between *B* and *D*, thus supporting *B* on a short leg. The strut from the lever *E* nearly filled the central hole in *D*, and extended to the bottom of the cavity in *A*. This cavity in *A* was made conical at the center so that the strut would always carry *A* concentric and poised, as it was raised. The thickness of *A* and *B* was about two inches. The lever was borne on knife-edges.

Steam is the only fluid experimented with. It was admitted at the nozzle *G*. Condensed water was let out at *H*.

In the experiments, weights were put on till the valve was raised, or, as in some cases, the weights were shifted along the graduated lever. The pressure of steam in the chamber upon the top surface of the valve was varied from 10 to 84 pounds per square inch by gauge, or from 25 to 99 pounds per square inch absolute. The results reduced to the valve are given in the plate where the circle dots were obtained by one series of observations, and the cross points by another, the two series being several weeks apart in points of time. The vertical scale at the left is for the steam gauge pressures in the chamber. The horizontal scale gives the number of pounds pressure per square inch of the cavity area, which was necessary to lift the valve. The figures given in this scale were reduced to the valve from the experimental data read off from the weighted lever, the weight of the lever, scale-pan, strut and valve being taken into account; but not the atmospheric pressure to which the cavity under the valve was exposed. Hence the figures in both scales are apparent pressures per square inch, one for the entire area of the six-inch circle of the valve, and the other for the area of the circle of the cavity, two and one-tenth inches in diameter.

The curve running among the dots is supposed to be drawn where the sum of the squares of all the distances from the line to the dots is the least, that is to say, that line is the probability line for all the observations, according to the theory of "*least squares*." It is assumed, however, that the line should run through the origin. From this line the figures in the first two columns of the following table were read off.

TABLE D.—*For a circular valve* 6 *inches in outside diameter, with a circular cavity* 2.1″ *diameter exposed to the atmosphere.*

APPARENT PRESSURE, LBS. PER SQ. IN. ON VALVE 6″ DIAM. $p_1 - p_2$	APPARENT PRESSURE, LB. PER SQ. IN. ON CAVITY OF VALVE, 2.1″ DIAM. p'	EQUILIB. AREA SUCH THAT $a'(p_1 - p_2)$ WILL JUST RAISE THE VALVE; SQ. INS. a'	DIAM. OF EQUILIBRIUM AREA; INS. d.
5	8.	5.6	2.6
10	17.	5.8	2.7
15	26.	6.0	2.8
20	36.	6.2	2.8
25	46.	6.4	2.9
30	57.	6.6	2.9
35	69.	6.8	2.9
40	81.	7.0	3.0
45	95.	7.3	3.0
50	112.	7.8	3.1
55	129.	8.2	3.2
60	150.	8.7	3.3
65	172.	9.2	3.4
70	198.	9.8	3.5
75	230.	10.5	3.7

A better notion of the quantities given in the table and plate perhaps can be obtained from Fig. 4, giving a section of the valve and its seat. Within the valve outline are drawn arching circles springing from the seat. These define the greatest and least equilibrium lines, which here are circles to the diameters 3.7″ and 2.6″ respectively, between which all the figures in the last column of the table fall.

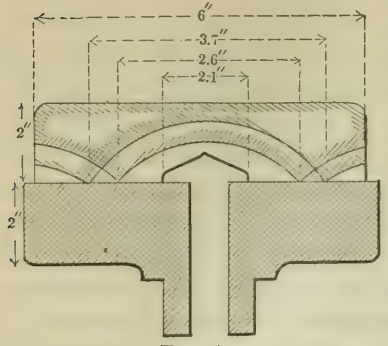


Fig. 4.

The interpretation of Fig. 4 is this:—For 75 pounds apparent pressure per square inch upon the top of the valve, the equilibrium circle is 3.7″ in diameter. That is, if the valve be taken from the chamber, and its seating face be turned off, or cut away with the exception of a sharp circular line to the diameter of 3.7″, so that when the valve is returned to its seat this circle is the only bearing of the valve upon its seat; then the same lifting force will be required to raise the valve from its seat as before, for this stated pressure of 75 pounds. Again when the stated apparent pressure is 5 pounds per square inch upon the top of the valve, then the same lifting force will raise it as when its face is cut away to a ring bearing of 2.6″ in diameter. In each case the atmospheric pressure is in full upon the cavity.

The relation between the pressures and areas may be expressed thus:

Let

p_1 = the absolute pressure per square inch within chamber;
p_2 = ordinary back pressure upon the cavity;
p^1 = lifting force per square inch of cavity, approximate;
P = mean absolute lifting pressure per square inch exerted by the creeping fluid between A and B, Fig. 3;
A = area of valve, here 6″ diameter;
a = area of valve cavity, here 2.1 diameter;
a^1 = equilibrium area.

Then,

$$p_1 A = p_1 (A - a^1) + p^1 a + p_2 a^1,$$

or,

$$a^1 (p_1 - p_2) = p^1 a$$

$$a^1 = a \frac{p^1}{p_1 - p_2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

As an example, take the pressure $p_1 - p_2 = 50$ lbs. for the 1st column of table. Opposite this, in the 2d column, we find $p^1 = 112$ lbs. These in the above formula, observing that $a = 3.46$ square inches, give $a^1 = 7.8$ square inches, as found in the 3d column, for the equilibrium area. But this formula is only applicable to this particular valve.

It seems desirable that the theoretical formulas given above for rectangular valves be brought to the test of verification or disproof, by this series of experiments. To do so, it will be necessary to deduce a general formula for circular valves in the same way as was that for rectangular valves, and then compare that theoretical formula for circular valves with the experimental values of the table.

If the theoretical results agree with the experimental ones, then not only is the theoretical formula for circular valves verified, but that for rectangular valves also.

From my paper on *A Rational System of Piston Packing*, above referred to, page 27, we may quote

$$p - p_2 = \frac{\delta f s l}{a} \frac{v^2}{2g} \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

as expressing the fall of pressure p to p_2 in a space conducting a fluid of invariable density δ, with the velocity v, where l is the length of the space, a its section, s the perimeter of its cross section, and f the coefficient of friction of the fluid upon the surfaces.

If the space be very thin with a thickness t, then for a unit's width we have $s = 2$ and $a = t$, so that

$$\frac{s}{a} = \frac{2}{t} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

Then for a very short length we may put dx for l, and dp for $p - p_2$, giving

$$dp = \frac{2\,\delta}{t} f \frac{v^2}{2g} dx. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

applying this to the part *abcd* of the space *ABCD*, where the thickness is constant, the velocity of the incompressible fluid will vary as it moves from *AC* to *BD*. This velocity will, in fact, be inversely proportional to the distance from *O*, so that if $v_2 =$ the velocity at *BD*, we have, if $r = BO$, $AB = b$, $AO = R$, and $aO = x$,

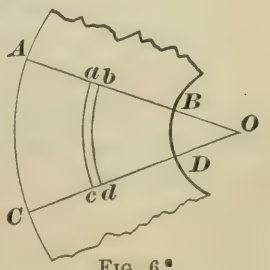


FIG. 6.

$$\frac{v}{v_2} = \frac{r}{x}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

Then, replacing v by its value,

$$dp = \frac{2\,\delta f}{t}\ \frac{v_2^2}{2g}\ \frac{r^2}{x^2}dx. \quad . \quad . \quad . \quad . \quad . \quad (7)$$

Integrating this between the limits aO and BO; or x and r, and p and p_2, we have

$$p - p_2 = \frac{2\,\delta f}{t}\ \frac{v_2^2}{2g}\ r^2 \left(\frac{1}{r} - \frac{1}{x}\right). \quad . \quad . \quad . \quad . \quad (8)$$

Here p is the pressure in the space $ABCD$, at the line ad, situated at the distance x from O. This line is circular, and may be considered as extending to the entire circle about O. Then the absolute lifting pressure upon a circular strip of width, dx, and radius x is

$$p\ 2\ \pi\ x\ dx,$$

and for the entire under surface of the valve A, the total absolute lifting pressure is

$$P\ \pi\ (R^2 - r^2),$$

a quantity which is equal to the integral of the last expression above. Writing this equation, and at the same time introducing p from equation (8) above, we obtain

$$P\ \pi\ (R^2 - r^2) = \int_r^R \frac{2\,\delta f}{t}\ \frac{v_2^2}{2g}\ r^2 \left(\frac{1}{r} - \frac{1}{x}\right) 2\ \pi\ x\ dx$$

$$+ \int_r^R p_2\ 2\pi\ x\ dx,$$

$$= \frac{2\,\delta f}{t}\ \frac{v_2^2}{2g}\ \pi\ r^2 \left\{\frac{R^2 - r^2}{r} - 2\,(R - r)\right\} + p_2\,\pi\,(R^2 - r^2);$$

whence

$$P = \frac{2\,\delta f}{t}\ \frac{v_2^2}{2g}\ r^2 \left\{\frac{1}{r} - \frac{2}{R + r}\right\} + p_2$$

$$= (p_1 - p_2)\,\frac{R}{R + r} + p_2. \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

since, from the equation (8) for pressure, x being made $= R$, and $p = p_1$, we have

$$(p_1 - p_2)\,\frac{Rr}{R - r} = \frac{2\,\delta f}{t}\ \frac{v_2^2}{2g}\ r^2.$$

Dividing by p_2, we obtain

$$\frac{P}{p_2} = \left(\frac{p_1}{p_2} - 1\right) \frac{R}{R + r} + 1, \quad . \quad . \quad . \quad . \quad (10)$$

in which $R = b + r$ (see Fig. 5). Or if the relation of the mean absolute lifting pressure P, due to the creeping fluid, is desired in its relation to p_1, the last equation is readily modified to that end, viz.:

$$\frac{P}{p_1} = \left(1 - \frac{p_2}{p_1}\right) \frac{R}{R + r} + \frac{p_2}{p_1}. \quad . \quad . \quad . \quad . \quad (11)$$

These equations are for an inelastic fluid like water. For elastic fluids, even for the isothermal condition, the analysis is too complex to be introduced here for the circular valve. But for rectangular valves of the form of the ordinary slide valve, the solution is already given above in connection with Figs. 1 and 2. See Tables B and C, and equation (1).

But in comparing tables A, B and C, we observe that the mean lifting absolute pressure P, divided by the absolute pressure p_1 upon the top of the valve, gives a ratio which is nearly the same in the three tables, for any one pressure, p_1. Or, more briefly, it seems to make but little difference whether the fluid pressing upon the valve, and creeping along under it, is compressible like air and steam, or whether it is more nearly incompressible, like water. Hence, according to equation (1), it appears that the equilibrium line is nearly at the same position whatever the fluid, though for high pressures the differences in position are greatest. This fact enables us to make use of equation (11), and the theoretical position of the equilibrium line determined thereby for incompressible fluids, in comparing our theoretical results with the results of experiment in Table D.

The comparison thus made will enable us to judge of the value of Tables A, B and C, for use in calculating the position of the equilibrium line in ordinary cases of the slide valve.

For our circular valve it is plain that equation (1) will not answer. But regarding Fig. 2 as a section of a circular valve such as shown in Fig. 3, then to find what part of the top surface of valve under the pressure p_1 will be balanced by the P upon the under surface AC, we have

$$P\ (\pi\ R^2 - \pi\ r^2) = p^1\ (\pi\ R^2 - \pi\ a^2),$$

the first member being the total lifting pressure due to the creep-

ing fluid between the valve and seat, and the second member being the top pressure p_1 multiplied by such a part of the top surface taken uniformly around the outer edge of valve, as shall just counteract that lifting pressure.

In the last equation, x is the radius of the circle of the equilibrium line. Hence the diameter of that circle is twice the value of x from that equation, or

$$d = 2\,x = 2\,R\sqrt{1 - \frac{P}{p_1}\left(1 - \frac{r^2}{R^2}\right)}. \quad . \quad . \quad . \quad (12)$$

Here d stands for the same as given in the last column of Table D. Combining (12) and (11), we obtain

$$d = 2\,r\sqrt{\frac{R}{r} - \frac{p_2}{p_1}\left(\frac{R}{r} - 1\right)}. \quad . \quad . \quad . \quad . \quad (13)$$

for the diameter of the equilibrium circle for circular valves as found by theory for inelastic fluids.

Now values of d calculated by (13) should agree with the experimental values of the last column of Table D, except for the differences due to the fact that the theoretical values are for inelastic fluids, while the experimental values were obtained by experiments with steam, differences which have already been shown to be small.

A comparison of the theoretical values from (13), with the experimental values of the last column of Table D will, therefore, be of interest. This comparison is given in

TABLE E.—*Comparing Theoretical and Experimental Diameters of the Equilibrium Line for $R = 3''$ and $r = 1.05''$.*

Appar. press. per sq. inch on valve. $p^1 - p_2$	Ratio of Pressures. $\frac{p^1}{p_2}$	Lifting & Seating Pressures. $\frac{P}{p_2}$	Diameter of Equilibrium Area. Experimental. d	Calculated. d	
5	1.33	.936	2.6	2.53	Probably 10 to 15 per cent. lower for elastic fluids.
10	1.67	.897	2.7	2.85	
15	2.	.871	2.8	2.92	
20	2.33	.852	2.8	3.02	
25	2.67	.838	2.9	3.09	
30	3.	.827	2.9	3.14	
35	3.33	.819	2.9	3.19	
40	3.67	.812	3.0	3.22	
45	4.	.806	3.0	3.25	
50	4.33	.801	3.1	3.27	
55	4.67	.797	3.2	3.29	
60	5.	.793	3.3	3.31	
65	5.33	.790	3.4	3.33	
70	5.67	.787	3.5	3.34	
75	6.	.785	3.7	3.35	
∞	∞	.741		3.56	

Though the last two columns are, for practical purposes, identical, yet it is to be remembered that perhaps a considerable difference is due to the fact of elastic and inelastic fluids as above mentioned.

To obtain some insight to the differences of calculated values for elastic and inelastic fluids, compare Table A for inelastic fluids with Table C for elastic fluids flowing isothermally; C being chosen in preference to B, because the differences are greater, but ranging here, however, mostly within 15 per cent. for values of $P \div p_1$. Though the law of velocity of the creeping fluid in circular valves differs from that in rectangular ones, giving cause for a difference in $P \div p_1$, for elastic and inelastic fluids which will not be exactly the same for rectangular as for circular valves, yet it is probable that these ratios of pressure will not be very far removed from each other. Assuming these differences identical for all forms of valve, and allowing the 15 per cent. range above mentioned, then putting in Eq. 12 values for $P \div p_1$, differing by 15 per cent. from those in Table E, we find that the corresponding calculated diameters of equilibrium areas are less by about 20 per cent. than those given in the last column of Table E. This throws the calculated values all to the other side of, or makes them smaller than, the experimental diameters of the equilibrium areas of the table, showing that for an elastic fluid these experimental diameters are high by about 10 per cent. This may perhaps be accounted for by the fact that during the experiments, when the chest was frequently opened to examine the valve, the seating surfaces were found to have upon them slight traces of a fine gray deposit, and this appeared to be most dense at and near the outer edge of the seating surfaces. The tendency of this would evidently be to keep the valve slightly elevated and to hinder the free entrance of the creeping fluid into the space under the valve and to favor its passage and escape after entrance, thus causing a greater effective pressure of valve upon seat and enlarging the experimental equilibrium areas to the figures observed, and to values higher than those calculated on the supposition of a purely elastic fluid flowing isothermally in a space of uniform thickness.

From these considerations it appears that the theoretical deductions are to be relied upon, and that the formulas resulting may be adopted in practice without hesitation. Formulas for elastic fluids and circular valves have not been worked out, but sufficient effort for them has been made to ascertain that such formulas would be

neither elegant nor convenient for use. But, fortunately, such formulas are mostly needed for rectangular valves with wide flanges on only two sides, as in slide valves for steam engines, for which case Tables A, B, and C will serve for all fluids and all requirements.

Practical formulas for calculating the equilibrium areas of ordinary rectangular slide valves of steam engines.

Let Fig. 6 represent a longitudinal section through one end of a double slide valve, with L the entire length over flanges, l the width of cavity, and q the width of the equilibrium area. It is evident that l must include cavities in the seat as well as in the valve, and perhaps bridges between. The side bearings of the valve, at the top and bottom of the cavity, are regarded as so narrow that they may be neglected.

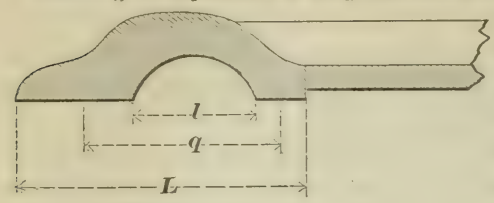


FIG. 6.

Then the upward pressure due to P against the entire under surface of the valve is

$$P\,(L - l),$$

and the part of the pressure upon the top of the valve which this equilibrates is

$$p_1\,(L - q),$$

which quantities are equal to each other. Equating and solving for q, we obtain

$$q = L\left\{1 - \frac{P}{p_1}\left(1 - \frac{l}{L}\right)\right\} \quad . \quad . \quad . \quad . \quad (14)$$

as the breadth outside of which the pressure p_1 is neutralized, and by which we are to multiply p_1 to obtain the effective pressure (absolute) upon the valve.

The total *effective* pressure of the entire half valve of Fig. 6 against its seat is, therefore,

$$Bq\,(p_1 - p_2) = B\,(p_1 - p_2)\,L\left\{1 - \frac{P}{p_1}\left(1 - \frac{l}{L}\right)\right\} \quad . \quad (15)$$

where B is the entire breadth of the valve.

As an example in application of (15), suppose a half valve be $L = 10''$, $B = 12''$, $l = 4''$, $p_1 = 90$ lbs. per sq. in., absolute, and $p_2 = 15$ lbs. per sq. in., or one atmosphere. Then Table A, for rect-

angular valves, gives $P \div p_1 = .583$, and the total effective pressure is, by (15),

$$12 \times 75 \times 10 \times \{1 - .583\ (1 - .4)\} = 5850 \text{ lbs} \quad . \quad (16)$$

where the total pressure upon the entire half valve is

$$12 \times 75 \times 10 = 9000 \text{ lbs.}$$

which latter, it appears, will never be exerted for pressing the seating surfaces together.

The resistance to sliding for the half valve will be

$$5850\, f,$$

where f is the coefficient of friction, the value of which no attempt is made to elucidate in this paper.

The result (16) would evidently have been the same had the cavity been placed at the middle in Fig. 6, as in ordinary slide valves.

For circular valves find d from equation (13), and Table E. Then the total effective pressure of valve against its seating surfaces, is

$$\tfrac{1}{4}\, \pi\, d^2\, (p_1 - p_2) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (17)$$

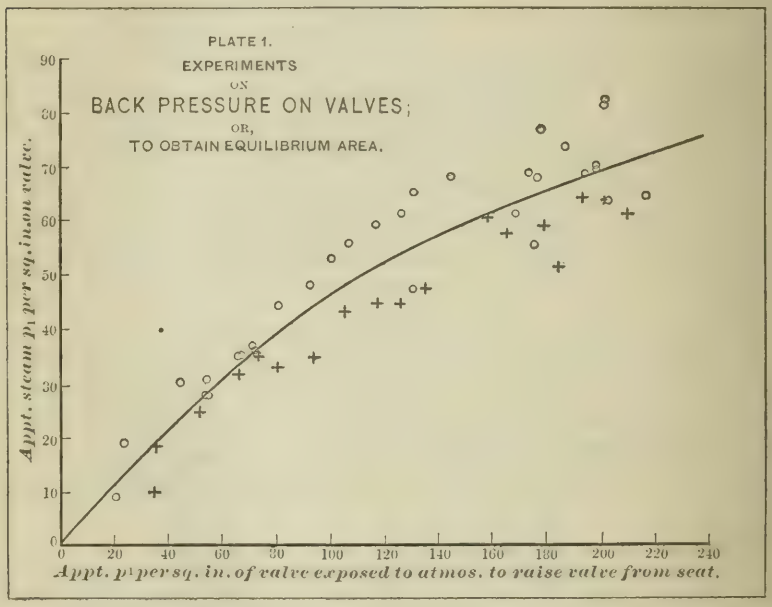
Conical valve seats, such as for wing valves of pumps, may be treated as circular surfaces where the slant height of the cone is R, etc., and d in equation (13) may be found. The cone is then to be developed, and such part of $\frac{1}{4}\, \pi d^2$ used as the developed cone is of 360°.

Where valves have an extraneous pressure applied, as in case of springs to assist in holding the valve upon its seat, it is evident that this pressure is to be added to that above obtained for effective pressure. Such spring pressure will in effect figure the same as the pressure on top of the valve over the cavity.

It may be remarked that the ratio of pressure $P \div p_1$ is for small lifts of valve independent of the thickness of the space between valve and seat. From this fact we are to conclude that the same force which starts the valve upward from its seat in lifting it, is to be continued until the space becomes so thick that the accelerative force required to give the escaping fluid its motion, becomes so great as to absorb an appreciable portion of the total head causing flow. The acceleration to be accounted for in this problem is that at entry to the space, and also along the space to the exit, the

accelerative force along the space between valve and seat would be nil for rectangular valves and inelastic fluids, but not for others. These points are important to a rational theory of perfect "pop" safety valves.

It is advisable to observe here that the experimental results given in this paper serve not only to confirm the theory of the equilibrium line, etc., for valves, but that the theory of packing rings as given in the paper on *A Rational System of Piston Packing*, above cited, based upon the same principles, also receives confirmation in the same degree.



BELTING TO CONNECT SHAFTS WHICH ARE NOT PARALLEL AND DO NOT INTERSECT.

BY

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(Read at the first regular meeting of 1882.)

HAVING found incomplete and inaccurate statements with regard to the setting of pulleys for twist-belts in some of our standard works on mechanism,* I have endeavored to investigate the subject more exactly.

The general law governing all cases of flat belting is, that the "point of departure" of the belt from one pulley must lie in the "belt-plane" of the other.

The following terms have been adopted for convenience:

Point of Departure.—The point Z (or Z'), Fig. 1, at which the belt leaves the pulley and enters upon the *Belt-tangent*, ZX' (or $Z'X$), which is the straight portion of the belt, tangent to both pulleys and reaching from Z (or Z') to the *Point of Arrival*, X' (or X). From this point the belt follows the *Circular Belt-arc* $X'Y'$ (or XY) in contact with the pulley. The plane of this arc is perpendicular to the pulley-axis, and will be called the *Belt-plane*. This, as will be seen, is parallel to, but not necessarily the same as, the central plane of the pulley. At the *Slipping point*, Y' (or Y) the belt begins to slip sidewise, running in a curve of double curvature, which we shall call the *Cylindrical Catenary*, from Y' (or Y) to Z (or Z'). This curve is cylindrical inasmuch as it lies on the surface of the pulley, while upon the development of that surface it is a common catenary with vertex at Y' (or Y).

* Among others we have this from Weisbach: "Zu diesem Zwecke hat man die beiden Räder, Fig. 190, so gegen einander zu stellen, und den Treibriemen so aufzulegen, dass *die gerade Verbindungslinie, AC, der beiden Ablaufspunkte in den Durchschnitt der beiden Radebenen hineinfällt*, indem alsdann offenbar der Ablaufspunkt eines jeden Rades in der Ebene des anderen Rades liegt. Diese Linie, AC, ist übrigens, wie leicht zu erkennen, dem kürzesten Abstande, MN, beider Axen gleich und parallel." [Die Mechanik der Zwischen und Arbeitsmaschinen, von Dr. Julius Weisbach. Dritter Theil, erste Abtheilung, S. 284. Zweite Auflage, Vieweg und Sohn, Braunschweig.] It is true that Fig. 190 represents apparently two shafts at right angles, but the statement is not confined to this shaft-angle.

An element of the cylindrical surface of the pulley drawn through Y' (or Y), is the axis of the catenary, and the parameter is the radius of the pulley divided by the co-efficient of friction between it and the belt. The circular belt-arc is tangent to it at Y' (or Y), and the belt-tangent at Z' (or Z). The *Perpendicular-tangent*, AA', is a limited line perpendicular to both the shafts, and at distances therefrom respectively equal to the radii of the pulleys. If the shafts be horizontal, and the pulleys be so set as to be tangent to a plumb-line, the perpendicular-tangent coincides with this line, and connects the point of tangency. This is indicated by the dotted position of the pulleys in Fig. 1. By means of a "shipper" on one of the belt-tangents we may force the belt to run in any desired position, having (for the other belt-tangent) its own point of departure and point of arrival, for which we will employ z and x, using the capital letters, Z and X, for the natural position only of the belt. By connecting all the points of arrival and of departure, we obtain curves of arrival and of departure. The *Curve of Arrival* is a curve of double curvature upon the cylindrical surface of the pulley, as is also the *Curve of Departure*. These curves may be defined geometrically as the loci of the points of tangency of the common tangent to two cylinders, the tangent to be drawn perpendicular to the axis of that cylinder on which the curve of arrival is to be generated. The upper and lower elements of each cylinder are asymptotes to the curves upon it. The horizontal projection of the intersection of the belt-planes will be denoted by s, and the locus of this point will be called the *Curve of Intersection*. With the "shipper" upon one belt-tangent we may generate the locus of s, and by shipping the other belt-tangent we may generate the locus of s'. In the natural position of the belt, s and s' will be the same, the curves intersecting in this point, which we will call S. The natural position, or position of equilibrium of the belt is that position in which it will run with no shipper upon either belt-tangent. The *Shaft-angle* is the angle θ, between the shafts, and the *Belt-angle* is the angle γ (or γ') which the belt-tangent makes with that shaft with which it is not at right angles.

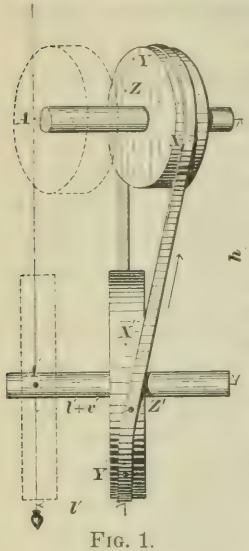


Fig. 1.

It has been sometimes assumed that the dotted position in Fig. 1 is correct for any shaft-angle; but it can be shown that it is not, either by examining the circumstances that determine the position of the belt or by constructing the simplest model. It has been stated inaccurately that a line, ZZ', which may be called the "*departure connective*," coincides with the intersection of the belt-planes, and still further that it is identical with the *perpendicular-tangent*. Neither statement is correct, though for shafts at right angles, the perpendicular tangent falls in the intersection of the belt-planes.*

The proper position of the pulleys may be found as follows:

Let, P and P', Fig. 2, be the upper and lower pulleys in horizontal projection; there will be four positions as shown. If the pulleys run as indicated by the arrow to the left, both points of departure will be projected near a; this is also the position of the pulleys in Fig. 3, where the course of the belt is also shown. By reversing both shafts, we obtain the position d, whereas if the lower (or upper) shaft alone be run backward, we have b (or c). These positions, however, correspond to the dotted positions in Fig. 1, and are therefore only approximate.

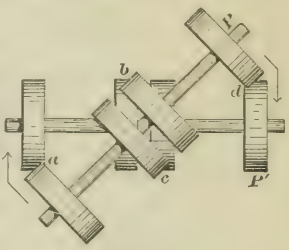
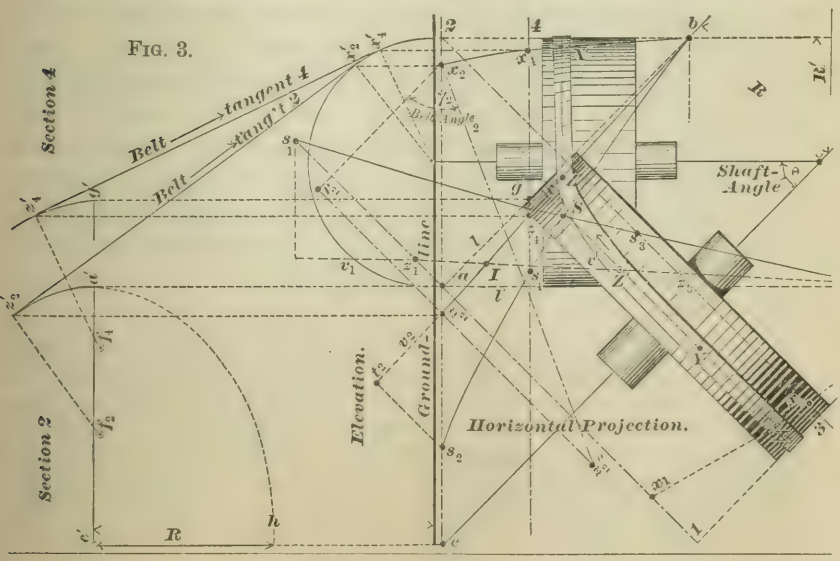


FIG. 2.

Fig. 3 shows the method of finding the exact positions on the as-



* See previous note.

sumption that we may neglect the stiffness edgewise of the belt, and also that the unequal tension on the edges of the belt does not curve its straight portions.*

Having given the sizes of the pulleys and the directions of their motion, also the angle and distance between the shafts, we suppose the pulleys to be extended into drums or cylinders, of which we draw the horizontal projections. These will consist of projections of the exterior elements, which will intersect each other in four points, a, b, c, and d, Fig. 2—a and b only appearing in Fig. 3. Pass now a series of planes 2, 4,—b, perpendicular to the lower shaft; these will cut circular sections of radius, R', from the lower cylinder, and from the upper, ellipses having R for a minor axis, and a major axis equal to $\frac{R}{\cos \theta}$. To the left of the (heavy) ground-line are shown the sections cut out by the planes 2 and 4. Plane 2 cuts the first element of P at a, and the center of its shaft at e; by projecting these two points to a height h above the ground line, we obtain the center, e', and vertex, a', of the ellipse. As a small part only of this curve is needed, we can approximate to this by a circular arc with its center at f_2. The ground line is here chosen at the height of the lower shaft, so that the section cut from P^1 appears as a semicircle. For plane 4 this semicircle is still the lower section, but the upper is found by projecting the point g (instead of a) to g', for the vertex of the ellipse. Having made these sections, we draw the belt-tangents, $z_2'x^{2'}$ and $z_4'x_4'$, which appear here in their true lengths, and obtain the points of departure, z_2', z_4', and of arrival, x_2', x_4'. Projecting these back, we get their horizontal projections, z_2, z_4, x_2, x_4, and, as it is clear also that b is both a point of departure and of arrival in horizontal projection, we may draw the horizontal projections of the "curve of departure," z_2z_4b, and of the "curve of arrival," x_2x_4b. The former curve belongs to the upper cylinder, and its projection is tangent to the horizontal projection of its outside element at b; the latter to the lower and tangent in the same way at b.

* The stiffness edgewise of the belt will tend to make the curve longer from Z to Y, but at the same time the unequal tension on the edges after the belt leaves the pulley at Z tends to curve the belt-tangent, and may thus more than counterbalance the former effect; in fact, with two pulleys, 12 in. and 16 in diameter, on shafts at right-angles and 7 feet apart, the tension was so unequal on the edges of a three-inch belt that the point of departure was more than an inch away from the belt-plane of the other pulley, and the belt bulged up in a wrinkle toward one edge before reaching the point of departure.

In precisely the same manner, by means of the planes, 1, 3, etc., perpendicular to the axis of the upper cylinder, we obtain a curve of arrival, $x_1 r_3 c$, (on the under side of the upper cylinder), and a curve of departure, $z_1 z_3 c$ (beneath the lower cylinder). The intersection I, of the projections of the two curves of departure, would be the projection of the intersection of the belt-planes, if the belt did not slip sidewise before reaching the curves of departure.

To allow for this slipping we must find the belt-angle, γ, which the belt tangent forms with the element of the cylinder passing through the point of departure.

For the point of departure b, $\gamma = 90°$, and it decreases gradually as the point of departure moves away from b, along the curve of departure. To find γ_2 for the point z_2, we notice that $z_2 r_2$ is the horizontal projection of the belt-tangent, and that a line through x_2, parallel to the elements of the upper cylinder, will have $x_2 r_2$ as its horizontal projection, and will make with the belt-tangent the angle γ_2, whose projection is the angle $r_2 x_2 z_2$. To find the true value of γ_2 we drop from z_2 the perpendicular $z_2 r_2$ upon $r_2 x_2$; this will be the horizontal projection of the perpendicular of the right-angled triangle, $z_2 r_2 x_2$, in space, of which the belt-tangent is the hypothenuse; if now we revolve this triangle about $r_2 x_2$ until it becomes horizontal, z_2, will fall at z_2'', this point being found by producing $r_2 z_2$ and cutting it with $x_2 z_2''$, made equal to the true belt-tangent length, $x_2' z'$, obtained from the section. We then find, $\gamma_2 = r_2 x_2 z_2''$.

It will be seen in Fig. 1 that l' is the distance from the plumb-line or perpendicular-tangent (marked a in Fig. 3) to the belt-plane, while $l' + v'$ is the distance to the point of departure, so that v' is the distance of this point beyond this plane: in other words, v' is the ordinate of the point of departure and of the catenary arc. According, then, to the laws of this curve, v is dependent upon γ in a very simple manner; in fact, if we put $\alpha =$ coefficient of friction, we shall have

$$v = \frac{R}{\alpha} \cdot \frac{1 - \sin \gamma}{\sin \gamma};$$

that is to say, if we construct a triangle similar to $x_2 r_2 z_2''$ with its perpendicular (side opposite γ) equal to $\frac{R}{\alpha}$ the parameter of the upper catenary, then v will be the difference between its perpendicular and hypothenuse. Having found v_2, (corresponding to plane 2, Fig. 3), we lay it off from z_2 to t_2, parallel to the upper axis, and

complete the right-angled triangle $z_2 t_2 s_2$, or we may simply lay off $z_2 s_2 = \frac{v_2}{\sin \theta}$. In the same way we obtain v_4 and find the point s_4, and complete this part of the work by drawing the curve of intersection through $s_2 s_4$ and b.

We proceed now in the same way for the lower pulley, remembering that $\frac{R'}{\alpha}$ is the parameter of its catenary, and obtaining the curve $s_1 s_3 c$. The intersection S of these two curves is the horizontal projection of the intersection sought of the belt planes, whose projections we can at once draw. Where these planes intersect, the curves of arrival and departure are the true points of arrival and departure, X, X', Z, and Z'. The slipping points, Y, Y', are not needed, but may be found from the fact that the length of the upper catenary arc is $\frac{R}{\alpha \tan \gamma}$, and of the lower $\frac{R'}{\alpha \tan \gamma'}$, γ and γ' being the angles corresponding to Z and Z'.

The manner in which the belt runs can now be understood: Arriving at X it follows the belt-arc to Y, where it begins to slip out of the belt-plane, so that by the time it arrives at Z it is a distance v from the plane. It now finds itself in the other belt-plane, and follows the belt-tangent to X', where it enters on the lower belt-arc, which it follows to Y' (not shown), and then commences slipping, so that when it reaches Z' it is v' away from the lower belt-plane and back again in the upper. $Z'X$ then completes the circuit to X.

It will be seen that the belt-planes do not lie in the centers of the pulleys, which, if "coned," should have their largest diameters in the belt-planes. The faces should also be wide enough to include the points of departure with a proper margin.

We will now deduce the equation of the catenary on the supposition that the belt slips enough on the pulley to prevent any standing friction.

In Fig. 4 we have the development (not drawn to scale) of that part of the upper pulley on which the belt runs; the curve of departure is at the top and the curve of arrival at the bottom. The curve sought is evidently tangent at the origin Y, to the axis of the abscissas YU, and at Z to the belt tangent, which makes an angle γ with YV. This axis is also seen to be the production of XY, the development of the circular belt-arc; YV, perpendicular thereto, is the axis of ordinates. The lower horizontal line

represents the outside element of the pulley, near the point of arrival X.

To investigate the nature of the curve YZ we will examine two consecutive elements of the cylindrical surface; these will be represented in Fig. 4 by the horizontal line passing through W. We will suppose these elements to be of the same width $= du$, and, in order to examine them closely, we will suppose the intersection at W to be magnified 8 times, which will give us Fig. 5.

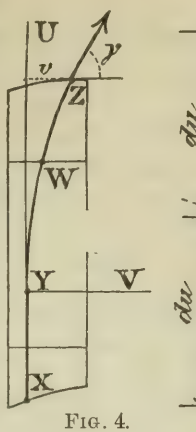


Fig. 4.

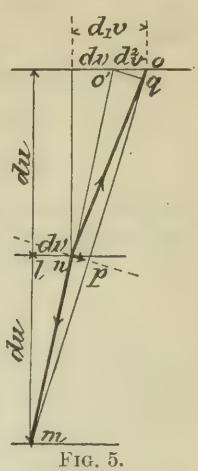


Fig. 5.

In this figure linear first differentials appear as finite quantities; mn and no are the two consecutive elements of the curve; these are supposed to be upon the undeveloped surface of the cylinder, and we shall therefore have m and o and the edges of the elements of the cylinder lying in the plane of the paper, while n and the junction of these elements will lie at a distance above the paper $= \frac{du^2}{2R}$. Inasmuch as the second element of the curve makes but a differential angle with the first, it should appear to fall upon no', which is the prolongation of mn; but in order to separate the lines to the eye it is drawn at no; this also makes $oo' = d^2v$ appear of a finite size, whereas it should not show upon this figure if drawn correctly. mn and no form two sides of a triangle, of which mo (in the plane of the paper) is the base, and np the altitude; the plane of this triangle is inclined to the plane of the paper, which latter is perpendicular to the radius of the cylinder.

To apply now the principles of mechanics to the problem:—At n we have two equal and opposite belt-tensions, represented by the arrows in the directions nm and no; as, however, no makes with mn a differential angle, these tensions will have a differential resultant in the direction np, Fig. 6 (np, Fig. 5, being its projection), as indicated by the arrow. If now we pass a plane through np and perpendicular to the paper, it will contain not only this resultant, but also the radius of the cylinder through n, as well as the intersections of the plane with the paper and with the surface of the cylinder. This section (indicated by the dotted line through np) is shown in-

finitely magnified in Fig. 6, where nn_1 is a portion of the cylinder radius through n, and the horizontal lines are the two intersections. In Fig. 6 second differentials appear as finite quantities.

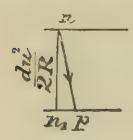


FIG. 6.

The belt at n, Fig. 6, being urged by a force in the direction np will slip along on the surface of the cylinder until the

$$\tan pnn_1 = \frac{pn_1}{nn_1} = \alpha = \text{coefficient of friction};$$

this gives us at once the value of the projection of pn on the plane of the paper (n_1p in Fig. 6 and np in Fig. 5),

$$pn_1 = \alpha \times nn_1 = \alpha \frac{du^2}{2R}.$$

Dropping now the perpendicular $o'q$ upon mo, we have its value twice that of $np = pn_1$,

$$o'q = \alpha \frac{du^2}{R},$$

but as $\frac{R}{\alpha}$ will be found to be the parameter of the catenary, we may at once write $o'q = \frac{du^2}{p}$.

We have now the triangle, $o'qo$, right-angled at q, and similar to mln, and therefore we may write the value of $d^2v = o'o$.

$$d^2v = \frac{du^2}{p} \cdot \frac{\sqrt{du^2 + dv^2}}{du} = \frac{du}{p} \cdot \sqrt{du^2 + dv^2}.$$

(The dv at o is of course greater than dv at n; to indicate this we have put at o, $d_1v = dv + d^2v$.)

As du is constant, this may be put in the following form for integration:

$$\frac{dv.d^2v}{\sqrt{du^2 + dv^2}} = \frac{du dv}{p},$$

which, integrated, becomes

$$\sqrt{du^2 + dv^2} = \frac{v + p}{p} du,$$

or,

$$dv = \frac{\sqrt{v^2 + 2vp}}{p} du.$$

To integrate again write this in the form,

$$\frac{dv}{\sqrt{v^2 + 2pv}} = \frac{du}{p},$$

and introduce a new variable by putting

$$\sqrt{v^2 + 2pv} = z + v,$$

which reduces the equation to

$$\frac{dz}{p - z} = \frac{du}{p}.$$

Integrating this and changing the result to the exponential form, we have

$$\frac{p - z}{p} = e^{-\frac{u}{p}},$$

in which the original variable, v, must be replaced: it will simplify the result, also, if we add to each member of the equation its own reciprocal. This gives, after reduction,

$$\frac{v + p}{p} = \frac{e^{\frac{u}{p}} + e^{-\frac{u}{p}}}{2},$$

as the equation sought of the curve. It is therefore the common catenary with a parameter $= p$.

Differentiating and remembering that

$$\sin \gamma = \frac{du}{\sqrt{du^2 + dv^2}}$$

we easily obtain the equation previously given.

$$v = p \frac{1 - \sin \gamma}{\sin \gamma}.$$

The length of the catenary arc is also easily found to be

$$s = p \text{ cotang. } \gamma.$$

We will now produce the equation of the curves of departure, and of the curves of intersection, which last also pass respectively through b and c.

In Fig. 7, which, like Fig. 5, is a horizontal projection, let the curves sought be referred to the oblique axes, aJ and aK, for the upper pulley (and aJ' and aK' for the lower). Let also k_1 be the ordinate of the curve of departure, and k_2 the additional distance to

the curve of intersection, so that $k_1 + k_2 = k$ is the ordinate to the curve, j being the common abscissa of both. aJ and aJ', are coincident with the outside elements of the upper and lower pulleys, while aK is perpendicular to the lower shaft, and aK' to the upper.

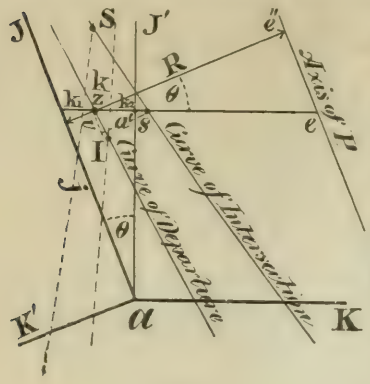


FIG. 7.

In Fig. 8 let $zg'ee'$ be a section through zse, Fig. 7, by a plane perpendicular to the lower axis, with a perspective of lines not in that section, drawn heavier when in front of the plane, and dotted when behind. R, in both 7 and 8, is the radius of the upper pulley to a point of departure z, and R makes with the horizontal plane through the axis the angle φ, as seen in Fig. 8: we will use φ as the independent variable, and express the js and ks in terms of it. In Fig. 8 the angles marked with an ∟ are right-angles, the semicircle shows the section cut out of the lower pulley, and the two curves shown as cut out of the upper pulleys are, the one an arc of the ellipse cut out by the plane of the section, $zg'ee'$, and the other a circular arc cut out by the plane through z perpendicular to the upper shaft.

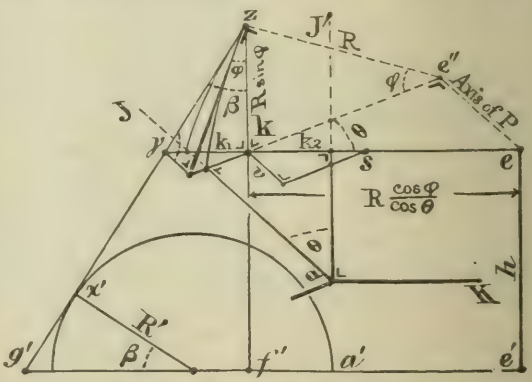


FIG. 8.

A comparison of the figures shows that in Fig. 7

$ze'' = R \cos$,

and therefore that

$$k_1 = \frac{R(1 - \cos\varphi)}{\cos\theta}, \quad \ldots\ldots\ldots \quad (I)$$

also, we see that

$$k_2 = \frac{v}{\sin\theta}.$$

Now the value of v depends upon γ, and γ depends upon φ; in fact, we found in the discussion of the catenary that

$$v = p\,\frac{1 - \sin\gamma}{\sin\gamma},$$

and in Fig. 8 we find

$$\operatorname{cotan}\gamma = \sin\varphi\tan\theta,$$

from which comes

$$\sin\gamma = \frac{1}{\sqrt{\sin^2\varphi\tan^2\theta + 1}},$$

so that by substitution we get

$$k = \frac{p}{\sin\theta}\left(\sqrt{\sin^2\varphi\tan^2\theta + 1} - 1\right).$$

Remembering also that

$$p = \frac{R}{\alpha},$$

we may write finally,

$$k = k_1 + k_2 = R\left[\frac{1 - \cos\varphi}{\cos\theta} + \frac{\sqrt{\sin^2\varphi\tan^2\theta + 1} - 1}{\alpha\sin\theta}\right]. \quad \text{(II)}$$

The value of j must also be expressed in terms of φ. We have, therefore, in Fig. 7,

$$ea' = \frac{R}{\cos\theta} - j\sin\theta.$$

But ea', Fig. 7, is the same as $e'a'$, Fig. 8, where it has the value

$$e'a' = e'f' + f'g' - g'a'.$$

These three distances are seen in Fig. 8 to be

$$e'f' = R\,\frac{\cos\varphi}{\cos\theta}$$

$$f'g' = zf'\tan\beta, \text{ but } zf' = h + R\sin\varphi,$$

so that

$$f'g' = (h + R\sin\varphi)\tan\beta.$$

$$g'a' = R'\,\frac{1 + \cos\beta}{\cos\beta}.$$

We find also in Fig. 8 that

$$\tan\beta = \frac{\tan\varphi}{\cos\theta},$$

and that therefore

$$\frac{1}{\cos\beta} = \frac{\sqrt{\tan^2\varphi + \cos^2\theta}}{\cos\theta};$$

substituting these values, and solving for j we obtain

$$j \sin \theta \cos \theta = R' \left(\sqrt{\tan^2 \varphi + \cos^2 \theta} + \cos \theta\right)$$

$$- R \frac{1 - \cos \varphi}{\cos \varphi} - h \tan \varphi, \quad . \quad . \quad . \quad . \quad \text{(III)}$$

I, II and III are therefore the equations for the curves of departure and intersection for P. Similarly for P' we have

$$k' = R' \frac{1 - \cos \varphi'}{\cos \theta}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(I')}$$

$$k' = R' \left[\frac{1 - \cos \varphi'}{\cos \theta} + \frac{\sqrt{\sin^2 \varphi' \tan^2 \theta + 1} - 1}{\alpha \sin \theta}\right], \quad \text{(II')}$$

$$j' \sin \theta \cos \theta = R \left(\sqrt{\tan^2 \varphi' + \cos^2 \theta} + \cos \theta\right)$$

$$- R' \frac{1 - \cos \varphi'}{\cos \varphi'} - h \tan \varphi', \quad . \quad . \quad . \quad \text{(III')}$$

The intersection S must satisfy at once II, III, and II', III', which may be expressed analytically by writing

$$j \sin \theta = k + k' \cos \theta, \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(IV)}$$

$$j' \sin \theta = k' + k \cos \theta, \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(IV')}$$

By first using IV and IV', and then II and II' we may reduce III and III' to two equations between φ and φ'; it will be easier, however, to use II, III and II', III' to draw portions of the curves of intersection, and thus to find S graphically.

When tables have been calculated for a particular co-efficient of friction, and it is desired to obtain results for a different and preferably greater co-efficient, it can be done with sufficient accuracy by including in the tables columns giving that portion of $j \cos \theta$ (or $j' \cos \theta$), which is the projection on j' (or j) of SI, Fig. 3 or Fig. 7, it being only this portion which varies when α is changed.

Those who may be disposed to test the practical accuracy of the positions obtained as above will confer a favor by reporting the results to the author. To put the matter in a convenient shape for any such tests, as also for practical use, the following partial tables have been prepared, with no pretension, however, to great accuracy.

To test the tables, narrow belts should be used, as no lateral stiffness has been allowed for.*

TABLES

For finding the positions of pulleys on non-intersecting, non-parallel shafts. The results are not given farther than 60°. For $\theta = 90°$ and 270°, $l_0' = 0$. The following is the complete notation, part of which is in the figures.

D' = diameter of lower pulley = 2 R'.

R and R' = radii of upper and lower pulleys.

h = height of upper shaft above the lower.

θ = angle between the shafts.

α = co-efficient of friction between belt and pulley.

$\alpha_0 = 0.2$ = the value of α employed in the tables.

l and $l' = j \cos \theta$ and $j' \cos \theta$ = distances of the upper and lower belt-planes from the perpendicular-tangent, *i. e.*, from the point a Fig. 3.

l_0 and l_0' = the values of l and l' for $\alpha = \alpha_0$ and $D' = 1$.

λ and λ' = the parts of l_0 and l'_0 dependent on the friction.

v, v', v_0 and v_0' = distances of Z and Z' from their belt-planes; the pulleys should therefore be made this much wider than is usual for parallel shafts.

For values of α and D' other than $\alpha = \alpha_0 = 0.2$, and $D' = 1$, we have, with sufficient accuracy,

$$l = \left(l_0 + \lambda \frac{\alpha_0 - \alpha}{\alpha_0} \right) D'$$

and

$$l' = \left(l'_0 + \lambda' \frac{\alpha_0 - \alpha}{\alpha_0} \right) D'.$$

Also

$$v = v_0 \frac{\alpha_0 - \alpha}{\alpha_0} D'$$

and

$$v' = v'_0 \frac{\alpha_0 - \alpha}{\alpha_0} D'.$$

If, then, all the linear quantities in the tables are supposed to be inches, they will correspond with a lower pulley of one inch diameter.

[*See previous note.]

$R = R'$

h	θ°	l_0	λ	v_0	l'_0	λ'	v'_0
2	15	.65	.31	.01			
	30	.41	.26	.04			
	45	.21	.16	.07			
	60	.15	.12	.18			
3	15	.37	.20	.01			
	30	.23	.16	.02			
	45	.12	.09	.04			
	60	.09	.07	.09			
4	15	.22	.11	.00			
	30	.14	.10	.02	$l'_0 = l_0$	$\lambda' = \lambda$	$v'_0 = v_0$
	45	.08	.07	.03			
	60	.06	.05	.05			
6	15	.11	06	.00			
	30	.07	.05	.01			
	45	.04	.03	.01			
	60	.03	.02	.03			
10	15	.06	.02	.00			
	30	.03	.02	.00			
	45	.02	.02	.00			
	60	.02	.02	.01			

$R = 2\,R'$

h	ζ^0	l_0	λ	v_0	l'_0	λ'	v'_0
3	15	.88	.41	.01	.87	.41	.02
	30	.55	.34	.03	.52	.32	.08
	45	.35	.26	.07	.30	.22	.16
	60	.24	.20	.10	.18	.15	.26
5	15	.43	.22	.00	.42	.22	.01
	30	.27	.18	.02	.26	.17	.04
	45	.17	.14	.04	.15	.12	.07
	60	.11	.10	.05	.09	.08	.12
7	15	.23	.12	.00	.23	.12	.00
	30	.16	.10	.01	.15	.09	.02
	45	.10	.07	.02	.09	.07	.04
	60	.07	.06	.03	.05	.04	.07
11	15	.10	.05	.00	.09	.05	.00
	30	.07	.05	.00	.07	.05	.01
	45	.04	.03	.01	.04	.03	.02
	60	.03	.02	.02	.03	.02	.03

$R = 3\ R'$

h	$\theta°$	l_0	λ	v_0	l'_0	λ'	v'_0
4	15	1.04	.50	.01	1.02	.49	.05
	30	.65	.41	.02	.59	.37	.12
	45	.44	.33	.05	.36	.26	.22
	60	.23	.17	.09	.17	.11	.40
7	15	.43	.22	.00	.43	.22	.01
	30	.35	.24	.01	.32	.21	.06
	45	.19	.16	.03	.16	.13	.09
	60	.13	.10	.04	.09	.07	.15
10	15	.20	.10	.00	.20	.10	.01
	30	.15	.10	.01	.14	.09	.03
	45	.10	.08	.02	.09	.07	.05
	60	.07	.06	.02	.05	.04	.08
16	15	.08	.04	.00	.08	.04	.00
	30	.07	.05	.00	.07	.05	.01
	45	.05	.04	.01	.04	.03	.02
	60	.03	.02	.01	.02	.02	.03

$R = 4\,R'$

h	δ^0	l_0	λ	x_0	l'_0	λ'	x'_0
5	15	1.09	.52	.01	1.06	.50	.04
	30	.72	.47	.02	.65	.41	.13
	45	.50	.38	.04	.39	.29	.32
	60	.36	.30	.06	.21	.17	.46
8	15	.50	.25	.00	.49	.24	.02
	30	.36	.25	.01	.33	.23	.06
	45	.25	.20	.02	.20	.15	.13
	60	.16	.14	.04	.11	.09	.20
11	15	.29	.15	.00	.28	.15	.01
	30	.21	.14	.01	.19	.13	.04
	45	.14	11	.02	.12	.09	.07
	60	.10	.08	.03	.07	.06	.11
17	15	.13	.07	.00	.13	.07	.00
	30	.11	.08	.00	.10	.07	.02
	45	.07	.06	.01	.06	.05	.03
	60	.05	.04	.01	.04	.03	.05

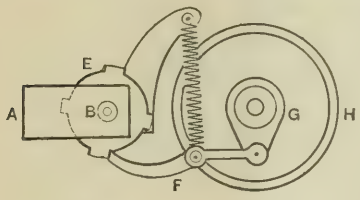
As the positions of Y and Y' are not needed in setting the pulleys, the lengths of the catenary arcs are not given in the tables. In some of the positions these arcs are of such extent as to render the positions impossible for low co-efficients of friction. Should the principle above developed be found to be in near accordance with experimental results, more complete tables may be calculated, which should include the lengths of the circular belt-arcs. This would furnish the data for an estimation of the varying amount of power which can be transmitted when the distance between the shafts is varied, this amount evidently depending to a large extent upon the lengths of the circular belt-arc; the limits of approximation of such shafting would thus become known.

A NEW FORM OF STEAM ENGINE INDICATOR.

BY

PROF. J. BURKITT WEBB, ITHACA, N. Y.

It has been my endeavor to devise a form of indicator which should work with high-speed engines, and I think I have hit upon a principle—a new principle, perhaps—which accomplishes the object. If, after having explained it, some should say that it is not new, I would say simply that that has been the history of all new things from ancient times to the present. In fact there have been instruments constructed on this principle, one of which was exhibited at Vienna. I had hoped to be able to bring to this meeting an indicator embodying the principle referred to, and showing its full operation; but, finding within the last few days that this would be impossible, I had constructed for exhibition to-night an instrument which will explain to you the fundamental principles, leaving the others for description at a future time.



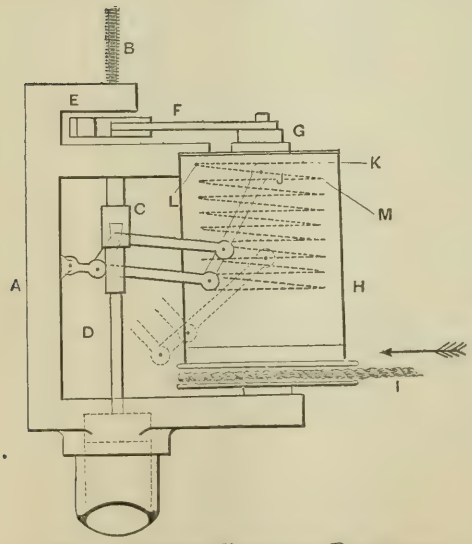


FIG. 1.—PARTIAL PLAN AND ELEVATION.

The instrument, as you will see, contains some of the parts of the ordinary indicator; these were put in to save time; they are quite unsuitable for it, and consequently, the indicator, although taking diagrams, does not take them as perfectly as desirable. It takes them, however, well enough to show the principle of the instru-

ment, and, perhaps, to prove its soundness. Here is a drawing of it (Fig. 1). A complete discussion of the principle and of the whole subject would take too long, so I shall confine myself to-night to the endeavor to make clear to you this principle alone, and should be glad to hear any objections to it which may occur to the gentlemen present. There are certainly some which will apply to the imperfect form of instrument shown.

We can best begin by considering the defects of an ordinary diagram. It is evident to every one having any acquaintance with the subject that when such a diagram is taken on a high-speed engine, instead of getting a normal form, we have, especially at the commencement of the stroke when the steam enters, an oscillation which lasts very often through the whole of the remaining diagram, or at least for some time; in fact, at every sudden change of pressure there must occur such an oscillation, due to momentum of the parts (see Fig. 2). Now I have endeavored to

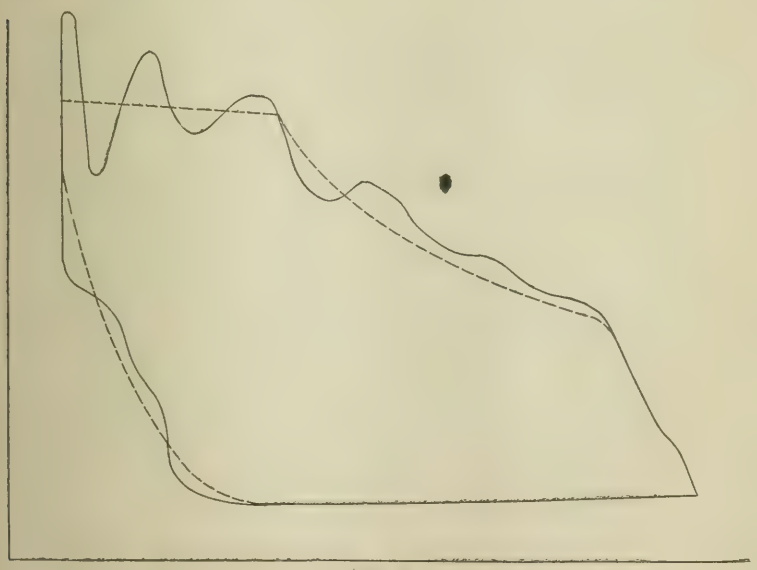


FIG. 2.

correct that upon this principle: Supposing that at any particular part of the vertical stroke of the indicator piston we can stop it and wait until the next stroke, when we will allow it to go on a short distance and stop it again and wait till the succeeding stroke, and then allow it to proceed, and so on. Now, if we can make the parts sufficiently light to act quickly, we can then get an accurate

diagram. How that would be done by this instrument will be explained; but before attempting this, your attention will be called to the diagram itself. This (see Fig. 3) is a diagram taken the day before yesterday on an engine with the cut-off blocked. It had an automatic cut-off, but it was blocked so as to make the expansion constant for a certain time, and it ran as hard as it could, up to 400, when things began to shake so that it could not be run faster. We have here this series of zigzag lines which I call the blank diagram. If the steam is shut off from the indicator, we have nothing further. Each line is made by one stroke of the engine, and if it runs at 400 it would be about three seconds with this instrument, and the diagram is finished. If, however, the cock is open, then instead of going all the way through over the blank diagram, as soon as we get down to the proper pressure, the pencil will begin to make also the diagram itself. Instead of following the 55 lb. horizontal line, it will jump up a short distance, depending on the construction of the instrument, and it will continue up until the pressure on the cylinder falls again to 55 lbs., when it will come back to the 55 lbs. horizontal and finish it out. The pencil will then return to the left side of the diagram on the diagonal line, and the process will be repeated until the card is complete. In Fig. 3 the exact course of the pencil may be traced over the whole card. In this diagram the expansion curve is too far to the right; this fault is due to the inertia of the parts of the indicator, upon which my attachment is placed. To remedy this a certain correction can be made in the card, but with an instrument constructed properly I think this error will be small enough to be neglected.

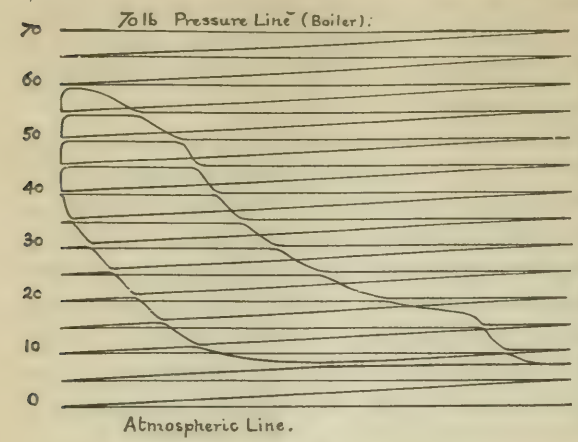


FIG. 3.

In Fig. 1 an ordinary indicator is shown with my attachment. The frame of the instrument is extended up to *e*, and a hole is made through it in which the screw *b* slides freely. This screw

has a nut, *e*, which is confined between the forks of the frame. The lower end of the screw has a forked head, *c*, which embraces the upper end of the piston-rod, and is attached to the same by means of a pin, which passes through holes in both; the hole in the fork is, however, slotted out a little larger than the pin, as will be seen hereafter. If, now, we revolve the nut *e*, the screw will draw up the piston against the spring—the usual spring, not shown, but contained in the indicator cylinder—until we have set the latter at any desired pressure. If this pressure be above the maximum pressure in the engine cylinder, the pin at *c* will remain resting on the bottom of the slot; but if it be below the same, then during any stroke of the engine it will remain there only so long as the cylinder pressure is below that of the spring, and it will jump to the top of the slot when the former exceeds the latter. The slot is made the right length to allow of a jump of 4 or 5 lbs., as shown in Fig. 3. To complete the arrangement we have only to add the pawl *f* and crank *g* mounted on the top of the indicator drum, *h*, and so arranged that during each backward stroke *f* shall revolve *e*, and thus let the screw *b*, with the piston and spring, gradually down. It is clear now that the action will be as follows: Having drawn the spring up to, say 70 lbs. (see Fig. 3), we shall get between that and 60 lbs. simply the blank diagram, of which the diagonal lines are due to the action of the pawl, *f*, after which we shall get the card, as shown.

On the instrument which you have in your hands there is no pawl, but there is another arrangement answering exactly the same purpose. The leverage is the leverage I found on the indicator, and it is very unsuitable. It multiplies too much—it multiplies six times.

This is one of the directions in which improvement has been made in the ordinary indicator, namely, in making the piston move through a short distance, with a large leverage to get cards high enough; and in reducing the height of the cards. A gentleman said to me, "What is wanted are higher cards." In this form we can get as high cards as we please, because the vertical motion is entirely independent of the motion of the piston.

Another trouble comes in, due to momentum: that is, in running the drum of the instrument, which can be avoided in various ways. One of the most necessary things in avoiding it is to run the drum by a string which pulls it in both directions. If a spring is put into the drum, and one string used, it will be stretched a great

deal more during its pull then when it is let back, and a change of phase will result. In the first instrument constructed, I used the ordinary drum, and in running at 430 got a diagram which I will illustrate [illustrating]. In an ordinary diagram a little of that effect might come in without being noticed; it would simply alter the shape of the curve a little, and you would not, perhaps, know that it was not due to some other cause, but in this all of it shows. (The diagram showed a decided change of phase. In a card three inches long this difference was $\frac{3}{32}$ of an inch.) This is an advantageous point in the method, because it enables any change of phase to be detected. In order to avoid that change in this instrument, I used a very light wood for the barrel, pivoted it at both ends, and put in two strings—that is, an endless string connected with the lever. I detected no change of phase whatever, and think, perhaps, up to 500 such an arrangement would be good.

The other improvements that I am attempting may be mentioned briefly. I want to produce a drum of metal, not a wooden drum, that shall not need to be very light, and yet shall run in perfect accord with the engine. I want to make the diagrams all of a certain length and height, so that with the same engine diagrams can be taken with pressures of 40, 50, or 100 lbs, and laid upon each other, and the changes of form seen.

I want also to get rid entirely of springs in the indicator, and think they can be avoided entirely, and the moving parts made lighter. That is a question for experiment.

DISCUSSION.

Mr. Oberlin Smith.—I want to ask Professor Webb if he can tell us anything about an arrangement for measuring the area of these diagrams, which is an improvement on the old methods.

Professor Webb.—That is also another addition which is not on this instrument. Perhaps I should have mentioned it. It is clear that if we measure the lengths of the horizontal lines included in the diagram, and add together those lengths, we have the area of the diagram—which may be done by taking such wheel as a blacksmith uses to measure a tire and running it over these horizontal lines, lifting it up when it leaves the diagram, and returning it when it reënters it. Such an arrangement can be attached to the instrument so that when the pencil rises this wheel will touch an oscillating arc, and you will have a more accurate measurement of the area than can be made in any other way. This motion of the pencil in

rising and falling need not proceed in the direction already indicated; it can be made in a direction perpendicular to the indicator card. When the steam rises above the pressure at which the spring is set, the pencil will be forced against the paper and will draw a line as long as the steam is above that pressure. This makes a diagram consisting of a lot of shading, as if we took an ordinary diagram and shaded the inside of it. It is immaterial, in using the measuring machine, which instrument is put on, because the principle is the same.

Mr. Charles E. Emery.—It is said that there is nothing new under the sun; but I am sure that this is entirely new to me. I feel grateful to Professor Webb for bringing it out. I think this is a principle which can be applied in other directions. As we look at a piece of mechanism of any kind, if we be apt in meeting new problems, we will adapt the features of that piece of mechanism to the new problem. I can see that there will be considerable labor necessary in developing this so that it will to some extent supersede the ordinary indicator, but I must say that I think it encouraging and worthy of effort. The nearest it that I have ever seen in my practice was in using the old Stillman-Allen indicator. We found, for instance, in the navy during the war, running at the high speed we had on gunboats, with a good deal of lead on the valves, the pencil would jump very high at the beginning of the stroke, and distort the diagram throughout, and I have frequently known a very good diagram to be obtained with a block of wood steadied so that the piston-rod would strike it at the right height—the diagrams, in fact, resembling very much those we get with Richards' indicator. That is the same principle applied only to the initial pressure. This is the application throughout the stroke, and really I think it will be brought to such a state of perfection that it will be of use to all, so that most of those who make a specialty of using indicators will want at least one instrument of this kind.

As one having had some experience with many mechanical devices—but as I am getting older, I dislike to go into intricate matters more than I did when younger—I would suggest that perhaps it is best not to put too many things on the instrument. Some of the details suggested here have already been tried, and difficulty found with them. For instance the form of parallel motion is one that Mr. Richards took hold of and abandoned. That of course has nothing to do with the principle. By the plan of simply

carrying up the piston and putting the pencil at the top directly in line with the piston, very good diagrams were got with naval engines at high speeds and initial pressures. Perhaps it is sufficient in this case to use no levers at all, and simply use a spring.

In regard to some of the suggestions that improvements were necessary, my experience would hardly warrant trying to get all cards of the same height. If there is any thing I dislike in the practice of young gentlemen in taking diagrams, it is their tendency to use a light spring so as to get a diagram of pretty good height. I have always insisted that they should use a 40-pound spring for everything. At once the card becomes an indication to the eye of the pressure of the cylinder. If a 40-pound spring is carried at every pressure, it is as accurate at 20 pounds as at 80. I think from one who has taken thousands and thousands of cards in his younger days, this suggestion may perhaps come with some force. Many starting in the use of the indicator are apt to get the cards too long for the barrel, when by allowing a little more leeway for stretch of string, etc., they can get a card which will keep its place on the barrel; this is a matter, however, that does not affect the present case.

Mr. Holloway.—I would like to ask the Professor if he has used this instrument on an engine on which the load varied very greatly indeed. Of course to get a card requires some dozen or more revolutions of the engine, as I understand it. What would be the effect if the engine had a variable load, and what sort of a card would it make working at full stroke part of the time and quarter stroke part of the time?

Professor Webb.—The curves would not join and form a continuous curve. Where the cut-off is automatic, the instrument would give parts of several ordinary cards, and the curve would not be continuous.

With reference to the remarks made by Mr. Emery, I agree with him entirely, although there is something more with regard to the height of the card than I mentioned. With reference to the pencil running directly up—that is the point in this indicator which I mentioned as being unfavorable; it multiplies six times, which is too much. In this form there is no reason why the spring should not be a long spring, and have a large amount of motion. There is no advantage gained in restricting the spring.

Mr. Oberlin Smith.—I would ask Professor Webb why it is not better in all cases to allow the pencil to approach and rest on the

paper so as to make a more definite diagram—whether there are any difficulties in the practical construction of an instrument in that form, on account of which it would not be better always to do that rather than to have the pencil jump up and down on the face of the diagram?

Professor Webb.—If the pencil rises and falls while it is in contact with the poper, the whole curve it makes can be seen. If the pencil is above the paper, and goes to meet the paper, then its distance from the paper must be constant and very small. I think perhaps it would be the better way; but I have made the instrument in both forms.

PART II.

PROCEEDINGS

OF THE

CLEVELAND MEETING,

JUNE, 1883.

AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

PROCEEDINGS OF THE CLEVELAND MEETING.

Local Committee of Arrangements.—J. F. HOLLOWAY, *Chairman;* C. F. Brush, W. M. Barr, Ambrose Swasey, N. S. Possons, W. H. Thompson, F. H. Richards, S. T. Wellman, E. H. Martin, John Walker, W. R. Warner, J. D. Cox, Jr.

Executive Committee.—S. T. Wellman, Ambrose Swasey, J. F. Holloway, J. D. Cox, Jr.

THE sessions of the Cleveland meeting were held in the rooms of the Vocal Society, in the City Hall. The opening session was held at 8 P. M., on Tuesday, June 12th. The names of the following members of the Society appeared on the Secretary's register:

Carl Angström	Worcester, Mass.
Wm. M. Barr	Cleveland, O.
Stephen W. Baldwin	New York City.
Wm. J. Baldwin	" "
J. Sellers Bancroft	Philadelphia, Pa.
Chas. A. Bauer	Springfield, O.
Alfred Betts	Wilmington, Del.
Henry L. Binsse	New York City.
Wm. H. Bone	Cleveland, O.
Chas. F. Brush	Cleveland, O.
J. H. Burnett	New York City.
Thos. W. Capen	Stamford, Conn.
Aug. W. Colwell	New York City.
C. C. Collins	Erie, Pa.
Geo. N. Comly	Wilmington, Del.
J. D. Cox, Jr.	Cleveland, O.
W. F. Durfee	Bridgeport, Conn.
Ezra Fawcett	Alliance, O.
Rimmon C. Fay	Hopedale, Mass.
C. M. Giddings	Massillon, O.
Wm. E. Good	Reading, Pa.
John J. Grant	Flushing, N. Y.
Homer Hamilton	Youngstown, O.
S. Ashton Hand	Toughkenamon, Pa.
F. F. Hemenway	New York City.
G. C. Henning	Pittsburgh, Pa.
Wm. Hewitt	Trenton, N. J.
J F. Holloway	Cleveland, O.

F. R. Hutton, *Secretary*.....New York City.
Gustav Kaffenberger.....Hamilton, O.
Wm. Kent.....Pittsburgh, Pa.
Charles Kirchhoff, Jr.....New York City.
Frank E. Kirby.....Detroit, Mich.
J. S. Lane.....Akron, O.
E. D. Leavitt, Jr., *President*.....Cambridgeport, Mass.
W. Barnet Le Van.....Philadelphia, Pa.
Edwin H. Martin.....Cleveland, O.
Geo. W. Maynard.....New York City.
Alex. Miller..... " "
T. R. Morgan, Sr.....Alliance, O.
Joseph Morgan, Jr.....Johnstown, Pa.
Wm. H. Odell.....Syracuse, N. Y.
Geo. E. Palmer.....Chicago, Ill.
Walter E. Parker.....Lawrence, Mass.
Edward H. Parks.....Providence, R. I.
J. F. Parkhurst.....Cleveland, O.
Wm. E. Partridge.....New York City.
Franklin Phillips.....Newark, N. J.
Thos. R. Pickering.....Portland, Conn.
N. S. Possons.....Cleveland, O.
Francis A. Pratt.....Hartford, Conn.
Thos. Whiteside Rae.....New York City.
Francis H. Richards.....Cleveland, O.
Luther A. Roby.....Cleveland, O.
S. W. Robinson.....Columbus, O.
A. Wells Robinson.....Montreal, Can.
John B. Root.....Greenpoint, N. Y.
Olin Scott.....Bennington, Vt.
Oberlin Smith.....Bridgeton, N. J.
Jesse M. Smith.....Detroit, Mich.
John E. Sweet.....Syracuse, N. Y.
Ambrose Swasey.....Cleveland, O.
Charles T. Thompson.....Philadelphia, Pa.
John Walker.....Cleveland, O.
W. R. Warner..... " "
W. O. Webber.....Lawrence, Mass.
J. Burkitt Webb.....Ithaca, N. Y.
W. H. Weightman.....New York City.
S. T. Wellman.....Cleveland, O.
Edward Weston.....Newark, N. J.
Jerome Wheelock.....Worcester, Mass.
Joseph J. White.....Philadelphia, Pa.
S. B. Whiting.....Pottsville, Pa.
J. R. Williams.....Pittsburgh, Pa.
Wm. C. Williamson.....Philadelphia, Pa.
C. J. H. Woodbury.....Boston, Mass.
C. C. Worthington.....New York City.

As invited guests of the Society, were present Messrs. H. M

Boies, J. W. Cole, R. C. Carpenter, and Messrs. Hewitt, Miller, Hutton, and many others.

Mr. Holloway called the Convention to order, and introduced Mayor JOHN H. FARLEY, of Cleveland, who delivered the following address of welcome:

Gentlemen of the Society of Mechanical Engineers:

Somewhat like yourselves, I am unused to this kind of work, so that on this occasion you will excuse me if I work from a templet. (Laughter.)

Gentlemen: Members of the American Society of Mechanical Engineers:—On behalf of the citizens of Cleveland I have the honor of extending to you a cordial welcome. The presence in our city of so many eminent students in that most useful branch of science—mechanics—is a great compliment to Cleveland, a compliment for which, as the representative of the city, I heartily thank you. The selection of Cleveland as the place of this meeting is a compliment not altogether undeserved, because there are few cities in the United States that can more fully appreciate the grand results attained from the high state of perfection in mechanics, that mixed science which you profess and so ably represent. Our citizens will undoubtedly use every effort to reciprocate the honor you pay them, by making your stay among us as agreeable and pleasant to yourselves as the interchange of views by the members of your Society must be beneficial to mankind in general.

You will find in Cleveland many institutions which will repay a visit of the student concerned in the working of metals, and in the various uses they bear to the economy of science, and the correlation and application of natural force to the general utility of man.

As mechanical engineering is the great impulse of commerce and civilization, hemmed in by no narrow lines of code ethics, limited only by the laws of natural philosophy, your coming together in fraternal fellowship must result in stimulating study in the sciences of nature and force. Hoping that nothing will occur to mar your deliberations, and trusting that our citizens, and our manufacturers in particular, will do all in their power to aid you, as I know they will, and to make you comfortable, I again welcome and thank you. (Applause.)

The President, replying to Mayor Farley's address of welcome, said:

Your Honor: On behalf of the Society which I represent, I thank you most heartily for your kind words of welcome. When it was announced that the meeting of the Society would be held in Cleveland, it was received with very general satisfaction, for we all had a desire to see the goodly city, the fame of which was in our ears; and our eyes have been gladdened by the sight. As you know, we are all a body of busy men; we are not given to much talk, and we prefer that our eloquence should be in deeds rather than words. Again I thank you. (Applause.)

Mr. J. F. Holloway, of Cleveland, O., then read his paper on the "Marine Engine of the Lakes, and a Device for Getting them off their Centers." He prefaced it with the following pleasant words:

Mr. Holloway.—Mr. President, I have been called upon to read my paper, and to show my little machine thus early in the evening for the purpose, I presume, of assisting in getting the business of this Society under way, and off its center.

I suppose it is true that large Engineering Societies, like large engines (I mean, of course, upright societies, and upright engines) are inclined, during long intervals of rest, to settle down on the lower center; and that it is necessary to "pry them off," before they will "go ahead." If with my little machine, I shall be able to do that much, I have no doubt that the papers that are to follow, will keep thought and discussion in motion, greatly to our pleasure, as well as to our profit.

No discussion followed the paper.

In the absence of the author, a paper by Mr. Howell Green, of Jeanesville, Pa., on the "History and Development of the Winding and Pumping Machinery of the Anthracite Coal Regions," was next read by the Secretary and elicited no discussion.

The next paper was by Mr. G. N. Comly, on "Economy in Lubrication of Machinery."

Following the reading of Mr. G. N. Comly's paper, the President said:

Discussion on this paper is in order, and the Chair hopes that there will be some discussion. It seems as though Mr. Holloway did not get the Society "off the center" and it needs "lubrication," which I suppose will come after awhile, and if we can run without "dry boxes" I hope there will be something said.

Discussion followed, in which Messrs. Grant and Woodbury took part.

After the conclusion of Mr. Woodbury's remarks, arose

The President.—The Chair regrets that it is necessary to close this discussion, as it is nearly time to "lubricate." (Laughter.) Mr. Holloway has an announcement to make.

Mr. Holloway.—Mr. President, I referred awhile ago to the difficulties sometimes met in starting the business for which we gather together. There is, however, another, and, as I think, important feature of our meetings which I would be glad to see started and under way as soon as possible. I refer to the social and friendly acquaintance and intercourse of the members, both new and old. I am sorry to say that I have no invention to lay before you for producing that result; but your Local Committee, who, I fancy, have had a good deal of experience in prying over engines with a bar under the arm of the fly wheel over a short bight, have been getting up an arrangement which they hope will serve as a "starter." (Laughter.) They desire to say while they have no bar on which to lay your arm, that if you will step into the next room they will furnish the "bite" (great laughter), or "bait." (Laughter.) I would move, then, that we take a recess and give their contrivance a trial.

Before putting the matter to vote, Mr. President, I would like to add a word or two more. It has been said that "too many cooks spoil the broth;" but I have not heard it said that too many engineers spoil having a good time. So the Local Committee has invited the Civil Engineers' Club of Cleveland to join us in this meeting, and in looking over this room I think we have just enough engineers to have a good time; and in order that you may know each other perfectly well, I take pleasure in introducing to you, gentlemen of the blue ribbons, the gentlemen of the white ribbons. (Applause and laughter.)

Mr. Grant.—I understood Mr. Holloway to say that we have no bar here. I think we have a Barr already belonging to the Society. (Laughter.)

Mr. Holloway.—Well, you can't get him under your arm. (Great laughter, and calls for Mr. Barr.)

Mr. Barr.—Mr. President, I don't know who is responsible for getting me into this scrape. It looks very much like a put-up job. (Laughter.) I suspect that Mr. Holloway has had something to do with it. Of course, you all understand from what Mr. Hollo-

way and others have said that we have endeavored to do our whole duty, knowing that this is the first time that the mechanical engineers have visited Cleveland, and in the natural order of things it will probably be some time before you get here again. We have not done very much; we have not elaborated very much the little that we have done; but we have endeavored to do the best that we could in order to make your stay here pleasant and agreeable; and not only for the engineers themselves, but I understand that the ladies of Cleveland have interested themselves and will take care of the visiting ladies, and whatever shall be left undone will not be through negligence at all, but simply because we did not exactly understand your needs or your desires.

Now, in regard to what Mr. Holloway has had to say in regard to the "bar" and the "bight," I can only say that this is the Barr and I suppose that he is now ready to present the bite. (Laughter and applause.)

The President.—The Chair would like to announce that the first paper at the morning session will be by Mr. W. F. Durfee, on "Balanced Vertical Engines." The Society will now adjourn for the "bite."

The Society then adjourned to the adjoining room, where a supper had been prepared by the Committee, which was fully enjoyed.

MORNING SESSION,

WEDNESDAY, JUNE 13TH, 10.30 A. M., IN CITY HALL.

The session of Wednesday morning, June 13th, was called to order in the City Hall at 10.30, for the transaction of business.

On motion of Mr. Durfee the reading of the minutes of the last meeting was dispensed with.

The President made a brief statement to the Society of the business done by the Council since the November meeting.

The Council has held meetings for transaction of business on November 24th, February 15th, April 5th, May 4th, and June 1st. The attendance at the meetings has been large at all sessions. The earliest matter acted on by the Council was the election of the Secretary for the current year. The Council appointed a special committee to nominate a Secretary, and the report of these gentlemen, after prolonged investigation of the qualifications of several

candidates, coupled with careful inquiry on the part of all the members of the Council, resulted in the unanimous election of Mr. F. R. Hutton, of New York, who has now filled the office since March 1st.

On April 5th, the accompanying resolutions were prepared in reference to the death of Mr. Peter Cooper, an honorary member of this Society, who had just passed away. The resolutions, signed by the President and Secretary, were sent to Mr. Cooper's family:

Whereas, In the death of Mr. Peter Cooper, one of the Honorary Members of the A. S. M. E., that Society has sustained a signal loss; and,

Whereas, Mr. Cooper had so identified himself with the progress and extension of applied science in this country as to call for the warmest recognition of every engineer: be it

Resolved, That we unite in expressing our gratitude for such a life as he was permitted to live: for its lessons of uprightness and integrity, for its example of usefulness to humanity and for its benefits to his city and to the country. Especially would we recognize the great benefit and help which he rendered to applied science, both through the schools of the Cooper Union and by the ever-ready assistance tendered to those trying to enter the paths of learning.

Resolved, That we express our recognition of the providential care which has so long preserved in activity the hand which fostered the great educational institution which it had founded.

Resolved, That we feel that in the death of Mr. Cooper there has passed away one of the pioneer spirits in the development of mechanical engineering as applied to railroad problems in this country. His successful experiments in the design and test of the locomotive engine were conclusive in settling the question of its future usefulness.

Resolved, That we recognize the advantages due to the early efforts of Mr. Cooper in the development of the manufacture of iron for structural purposes.

Resolved, That while we unite with the public expressions of loss in the death of Mr. Cooper, we also tender our sincere sympathy to those to whom it comes as a sore personal bereavement.

Resolved, That a copy of these Resolutions be sent to the family of Mr. Cooper, and entered on the minutes of the Society.

The matter of the revision of rules, in accordance with the Society's resolution passed in November, has received careful consideration from the Council. The president has appointed, with the concurrence of the Council, the following members as a committee of revision:

W. P. Trowbridge, Coleman Sellers, John E. Sweet, C. J. H. Woodbury and J. C. Bayles.

The committee for nominating officers for the coming year has also been appointed with the concurrence of the Council. It consists of Washington Jones, John C. Hoadley, H. R. Towne, S. T. Wellman and Irving M. Scott.

The Secretary then read the report of the tellers who canvassed the votes for membership.

Messrs. Chas. E. Emery and C. J. H. Woodbury, appointed tellers by the Council under Article XII of the rules as amended at Hartford, reported, June 1st, the election of the following gentlemen as the result of the ballots sent to the membership:

MEMBERS.

Angstrom, Carl, Worcester, Mass.
Bennett, Edwin H., Elizabeth, N. J.
Betts, William, Wilmington, Del.
Bone, Wm. H., Cleveland, Ohio.
Brown, Alexander E., Cleveland, Ohio.
Burgdorff, Theodore F., Washington, D. C.
Capen, Thomas Wells, Stamford, Conn.
Clarke, David, Hazleton, Pa.
Cummer, F. D., Cleveland, Ohio.
Davison, Henry J., N. Y. City.
Dean, F. W., Cambridge, Mass.
Dudley, Chas. B., Altoona, Penn.
Eastwick, George S., New York.
Edson, Jarvis B., North Adams, Mass.
Fawcett, Ezra, Alliance, O.
Fay, Rimmon C., Hopedale, Mass.
Fitch, Chas. H., Stamford, Conn.
Good, Wm. E., Reading, Pa.
Henney, J. B., Stevens Point, Wis.
Hillman, Gustav, City Island, N. Y.
Hoe, Robert, Jr., New York.
Hollingsworth, Sumner, Boston, Mass.
Kaffenberger, Gustav, Hamilton, Ohio.
Kettell, Chas. W., Charlestown, Mass.
Landreth, Olin H., Nashville, Tenn.
Leggett, M. D., Cleveland, O.
Lipe, Chas. E., Syracuse, N. Y.
Miller, Lebbeus B., Elizabeth, N. J.
Miller, Lewis, Akron, Ohio.
Murray, S. W., Milton, Pa.
Norton, Harold P., Washington, D. C.
Palmer, Geo. E., Chicago, Ill.
Parkhurst, John F., Cleveland, O.
Pitkin, Julian H., Canton, Ohio.
Robinson, A. Wells, Montreal, Canada.
Roby, Luther A., Cleveland, Ohio.
Scheffler, F. A., Paterson, N. J.
Scott, Olin, Bennington, Vt.
Seley, Chas. A., St. Paul, Minn.
Sinclair, Angus, Cedar Rapids, Ia.
Smith, Jesse M., Detroit, Mich.

STEARNS, THOMAS B., New York City.
STILLMAN, OSCAR B., Boston, Mass.
STRATTON, E. PLATT, College Point, Long Island, N. Y.
SWAIN, JOHN D., Nashua, N. H.
THOMAS, SAMUEL, Catasauqua, Pa.
VENABLES, JOHN HAMSON, Toronto, Can.
WATTS, GEORGE W., Scranton, Pa.
WEBSTER, HOSEA, JR., Brooklyn, N. Y.
WHEELER, HERBERT A., St. Louis, Mo.
WILLIAMS, J. R., Pittsburgh, Pa.
WILLSON, FREDERIC N., Princeton, N. J.
WOODS, ARTHUR T., Washington, D. C.
ZANE, ABRAHAM V., Washington, D. C.

JUNIOR.

CONANT, THOS. P., New York.

ASSOCIATE.

EVANS, EDWIN T., Buffalo, N. Y.

PROMOTION TO MEMBERSHIP.

HOLLERITH, HERMAN, JUNIOR, A. S. M. E., Boston, Mass.

The President.—It will be seen that the total number of members elected was 54. There was also one junior, one associate, and one promotion. It will be interesting to note here the growth of the Society. In January, 1883, the number of members was 357; additions to this date number 56, making a total membership of 413. The previous yearly additions, at two or three meetings, have been but 60 per annum.

It should be stated here that the Council having neglected to record their names as seconders on the applications of several gentlemen duly proposed, from personal knowledge, the Secretary was directed to add the names of Messrs. Leavitt, Emery, Trowbridge, and Woodbury as may be necessary to bring out all due conformity to the rules.

The next matter is a Report from the Treasurer, which the Secretary will read.

The Secretary then read the following report:

TREASURER'S REPORT

OF AMERICAN SOCIETY OF MECHANICAL ENGINEERS, JUNE 11, 1883.

1882.		
Nov. 2.	Balance on hand	$7 58
" 30.	Receipts during this month	1,806 46
Dec. 31.	" " "	469 54

1883.	Amount brought forward	$2,283 58	
Jan. 31.	Receipts during this month	323 96	
Feb. 28.	" " "	417 72	
Mar. 31.	" " "	436 33	
Apl. 30.	" " "	81 40	
May 31.	" " "	290 28	
1882.			
Nov. 30.	Disbursements during this month		384 10
Dec. 30.	" " "		1,815 46
1883.			
Jan. 31.	" " "		182 00
Feb. 28.	" " "		257 53
Mar. 31.	" " "		518 53
Apl. 30.	" " "		250 46
May 31.	" " "		378 07
	Balance, June 1st		47 12
		$3,833 27	$3,833 27

Since June 1st there has been received thirty-one and $\frac{40}{100}$ dollars, thus making balance of cash on hand at this date seventy-eight and $\frac{52}{100}$ dollars ($78.52).

There is still one U. S. Government Bond of the face value of one thousand dollars, held as an invested fund.

There are unpaid audited bills in my hands amounting to three hundred and sixty-three and $\frac{66}{100}$ dollars (363\frac{66}{100}$), a portion of which is for services of the Secretary of the Society. There is also due the Treasurer the sum of one hundred and fifty dollars ($150) for clerk hire to June 7.

There is due from the membership at this date for initiation fees and annual dues the sum of eight hundred and thirty-nine dollars ($839).

All of which is respectfully submitted.

CHAS. W. COPELAND,
Treasurer.

The President.—The next matter of business is a statement from the Publication Committee; if Mr. Stirling, its chairman, is present, he will please read it. If not, the Secretary will read it.

The Secretary.—The Secretary will simply make a verbal statement that Volume III., which is the complete proceedings and transactions of the Philadelphia meeting of April, 1882, will be sent to the membership next week; that Part 1st of Vol. IV. which is the proceedings of last November, can be sent to the membership in a few weeks' time if desired. The volume is entirely completed; it

simply remains to be bound according to the wishes expressed by the membership to the Secretary's office. It would seem preferable in most cases to delay the first part at this late date until the proceedings of this meeting can be bound up with it. The reprinted papers from the New York meeting of 1883 will be sent out very shortly.

After the conclusion of the business matters, the President announced the paper by Mr. W. F. Durfee, of Bridgeport, Conn., on "A Balanced Vertical Engine." The discussion was by Messrs. Henning, Scott, Le Van, Webb, Comly, Hamilton, W. J. Baldwin, Sweet, and Leavitt.

At the close of the discussion, the President said: If there is no further discussion on this paper, I will call for a paper by Mr. W. E. Ward, of Portchester, N.Y., on "Beton in Combination with Iron as a Building Material." Mr. Woodbury has kindly consented to read this paper, Mr. Ward being detained by the illness of his business partner. Mr. Woodbury then read the paper, and Messrs. Weightman, Root, Comly, and Thompson took part in the discussion.

At the close of the debate the President announced the paper by Mr. Towne, of Stamford, Con., which was read by Mr. Capen.

Mr. Morgan, of Alliance, gave it discussion until the hour of recess.

AFTERNOON SESSION,

JUNE 13TH, 2.30 P.M., IN CITY HALL.

Society called to order by the President.

The President.—Before continuing the discussion on Mr. Towne's paper, the Chair desires to remark that he trusts that the members will see the necessity of confining themselves to the intrinsic merits of the subject under discussion. We are apt a little, all of us, to be prejudiced in favor of our own particular hobby-horse, and while we wish to get at the merits of all specific devices, the great thing is to get at the truth of the subject. We all know that there are a great many different ways of accomplishing a given object. It is possible that there may be one best way, though in our experience we have often seen two. I remember an old engineer who said he wished there was only one way to do a thing, it would save him a lot of time. (Laughter.)

I trust in the discussion this afternoon, that view will prevail—that we shall have the advantage of the experience of those who are familiar with the subject, and that they will not confine themselves to any specific device as being the best, but give us the merits and let us as a body judge. (Applause.)

The discussion on Mr. Towne's paper was continued by Messrs. Durfee, Walker, Collins, O. Smith, Capen and Morgan.

A paper by Mr. G. W. Maynard, of New York, on the "Bower-Barff" Process, was next read, eliciting discussion from Messrs. Henning, O. Smith, Partridge and Hand.

The paper by Mr. William J. Baldwin, of New York, on "Standard Cast-iron Fittings" was discussed by Messrs. Barr, Le Van, Walker and Grant.

A paper by Mr. William Kent, of Pittsburgh, on the "Evaporative Value of Bituminous Coals," elicited discussion by Mr. Le Van.

Mr. C. C. Collins, of Erie, Pa., read a paper on "Balanced Valves;" and Prof. Webb, of Ithaca, N. Y., presented a paper, illustrated by models, upon "Reuleaux's Kinematic Models." The models were kindly loaned by the Trustees of Cornell University from their collections.

After Prof. Webb had read his paper,

The President.—As the hour for adjournment is close at hand, we shall hardly have time thoroughly to discuss this paper. I do not know who among us would be able to discuss it very thoroughly unless he has followed the subject very closely, as Prof. Webb has.

Mr. Holloway then made an announcement as to the excursion of Thursday, and in closing said: "I have a piece of very excellent news which I am sure you will very heartily enjoy. I have a telegram dated Hoboken, N. J., June 13th:

"'The Stevens Institute of Technology confers the Honorary Degree of Doctor of Engineering on President Leavitt at its Commencement.

"'(Signed) R. H. Thurston.'"

(Prolonged applause.)

The President.—Gentlemen, there have been Doctors of Medicine and Doctors of Divinity in our family, but this is the first instance, I believe, of any degree of this sort, and I suppose I must thank the Society for electing me to this office for the degree; and I do most heartily thank you, and trust that I shall be worthy of it as far as in my power. I certainly shall try to be. (Applause.)

The Society then adjourned.

In the evening, at the Opera House, the members attended a reception tendered them by the citizens of Cleveland. The Opera House, kindly tendered by Mr. M. A. Hanna, was handsomely draped, and was filled with a very hospitable throng. Everything was done to make the visitors feel at home; the music was very enjoyable, both orchestral and vocal, and a collation was served later in the evening.

Thursday, June 14th, was devoted to excursions.

By the kindness of Mr. R. F. Smith, Assistant Manager of the Cleveland and Pittsburgh R. R., a special train was put at the service of the Society. It left the Union Depot at 9.15 A. M., carrying over 150 of the members and their friends. The first point visited was the Otis Iron and Steel Works, where, under the guidance of Mr. Charles A. Otis and Mr. S. T. Wellman, the open hearth furnaces and rolling plant were inspected. Special interest centered around the plate mill and the devices for charging the rotary puddler. Thence the train proceeded to the Cleveland City Forge and Iron Co., where, piloted by Messrs. Coe and Ely, the members saw shaft forging by helve hammers, and the special forging of coupling links. At the Cummer Engine Works, guided by Messrs. Cummer and Barr, interest centered around the special tools for spacing stud-holes in flanges and the construction of the horizontal governor. Thorough inspection was next allowed of the Union Steel Screw Works, by the courtesy of Messrs. Fayette Brown and Bidwell. At the Brush Electric Works, Messrs. Stockley and Possons received the members as they alighted from the train, and showed every attention to their guests. At the shop of Messrs. Warner & Swasey, interest centered around the running gear for a 40-foot observatory dome, which, when fully loaded, could be set revolving by a pull of 30 lbs. The special device for planing segments was then noticed. After a visit to the very extensive malleable iron foundry of the Cleveland Malleable Iron Works, the party were taken out to Newburg, and were received at the gate of the Cleveland Rolling Mill. Under the leadership of Messrs. Chisholm, Walker and Martin, the successive heating furnaces, the Bessemer steel and open hearth plants, and the Blooming mill were visited, and especial interest was shown in the continuous wire-rod mill. After visiting the mill for shapes, the Society was escorted to a luncheon served in a large hall of the town. Not a little merriment followed remarks complimentary to the "Martin" process, through which its guide had carried the Society, involving the abundant use of "plate."

After luncheon, the excursionists boarded a train tendered by Mr. J. M. Ferris, of the N. Y. P. and O. R. R., and visited the new Central Furnace of the Rolling Mill Co. This furnace is now producing an average of 1,500 tons a week, and the members were privileged to arrive there in time to witness one of their large casts. Thence visits were paid to the Ore Docks, where Mr. A. E. Brown's Hoisting and Conveying Plants were shown in operation. A visit to the two pump-houses of the Water Works showed the members the Cornish and Worthington pumps for supplying the city, and after leaving their train, the members were escorted to examine the viaduct and its swing bridge. At that point the party separated.

During the time of the visits to the shops, etc., Cleveland ladies had accompanied the goodly number of lady visitors in a pleasant drive to and through the Lake View Cemetery, the grounds of Adelbert College, and the private park of J. H. Wade, Esq. They returned delighted with the city, their hosts and their drive.

EVENING SESSION.

JULY 14TH, 8 P. M., IN CITY HALL.

The session of Thursday evening, June 14, was called to order a few moments after eight o'clock by Prof. Sweet, in the following words:

GENTLEMEN:—In the absence of the President, it has devolved on me to call the meeting to order, as the Secretary thinks it is best to go on. The first business will be a paper by Mr. Oberlin Smith, of Bridgeton, N. J., on "Spiral Springs: Compressive and Tensile."

Mr. Oberlin Smith then read his paper and the discussion upon it was participated in by Messrs. Robinson, F. H. Richards, Webb, Grant, Pickering, and Leavitt. After the President had returned to the chair, Mr. G. C. Henning, of Pittsburgh, Pa., read a paper entitled, "Some Notes on Steel," and Messrs. Leavitt and Le Van took part in the discussion which followed. Mr. W. F. Durfee, of Bridgeport, Conn., then read a paper on "Machinery for Maneuvering Clutch Couplings," which was illustrated with a handsome colored drawing. Mr. Walker took part in the discussion which followed.

The hour for adjournment having nearly arrived, the Secretary, in the absence or by the wish of the authors, read the following papers by title:

Julius S. Hornig, Jersey City, N. J.: "Economy in Subdivision in Installation and Operation of Machinery at varying demand."

Gram Curtis, New York: "Remarks on the Ordinary Form of Bessemer Ingot Cranes."

John E. Sweet, Syracuse, N. Y.: "On a New Method of Constructing a Crank Shaft."

R. H. Thurston, Hoboken, N. J.: "Note on the Water Hammer in Steam Pipes," with discussions to accompany the paper by Messrs. W. P. Trowbridge and Chas. E. Emery.

S. S. and W. O. Webber, Lawrence, Mass.: "A New Form of Balance Dynamometer."

T. W. Rae, New York: "Some of the Mechanism employed in Multiplex Telegraphy."

John E. Sweet, Syracuse, N. Y.: "On a new Method of Casting Flange Pipe."

R. H. Thurston, Hoboken, N. J.: "Note on the Effect of Prolonged Stress on Iron."

After the reading of the above papers by title, the following resolutions were offered, duly seconded, and carried:

By Mr. John B. Root:

Resolved, That the thanks of the American Society of Mechanical Engineers are due to J. H. Farley, Esq., and to the citizens and ladies of Cleveland for the cordial welcome and kind treatment extended to them on the occasion of their visit to the city of Cleveland, and especially are the thanks of the Society due for the great pleasure accorded them on the occasion of the reception of June 13th.

By Mr. W. E. Partridge:

Resolved, That the thanks of the Society are due and hereby tendered to M. A. Hanna, Esq., for the use of his Opera House, and for personal services on the occasion of the Citizens' Reception, on June 13th, and for his assistance in making that occasion one of great pleasure.

By Mr. F. A. Pratt:

Resolved, That the thanks of the American Society of Mechanical Engineers are due to the Otis Iron and Steel Co., Cleveland City Forge and Iron Co., Cummer Engine Works, Union Steel Screw Works, Brush Electric Works, Warner & Swasey, Cleveland Malleable Iron Works, Cleveland Rolling Mill Co., at their mill and furnace, and to Alexander Brown, Esq., and others representing the Ore Docks, for courtesies extended during the Society's visit to their various establishments.

By Mr. C. J. H. Woodbury:

To R. F. Smith, Esq., Manager, and to the Cleveland and Pittsburgh Railroad Company, and to J. M. Ferris, Esq., Manager New York, Pennsylvania and Ohio Railroad Company, for the use of excursion trains by which the Society of Mechanical Engineers were enabled to visit so many of the manufactories of the city, we desire by this resolution to return our most hearty thanks.

By Mr. W. F. Durfee:

Resolved, That the Society return thanks to the Faculty of Adelbert College and to J. H. Wade, Esq., for the cordial invitation extended to visit that institution; and that the thanks of the Society are also due to the Deering Seamless Barrel Co., to the Cleveland Stained Glass Co., and to many others for invitations to visit their works, and for courtesies shown to individual members during the session.

By Mr. Oberlin Smith:

Resolved, That we tender the thanks of the Society to John Whitelaw, Esq., of the City Water Works, to R. Doty, Esq., Chief Engineer of the Water Works, and to B. F. Morse, Esq., City Engineer, for courtesies shown the Society while visiting the Water Works and the Viaduct.

By Secretary F. R. Hutton:

Resolved, That the thanks of this Society be tendered to the Civil Engineers' Club of Cleveland for its courtesies extended and assistance given, and for their attendance and interest in our sessions.

By Prof. J. B. Webb:

Resolved, Thatthe thanks of the Society are due to the Executive Committee of the local members for the complete arrangements made for our entertainment, and for the most admirable manner in which they have been carried out during the day which has been devoted to excursions, and which has been so much enjoyed by all.

Resolved, That the Secretary be directed to send copies of these resolutions to the gentlemen mentioned.

Mr. Le Van further moved a special vote of thanks to those ladies of Cleveland whose attention to the visiting ladies had given so much pleasure. His motion was duly put and carried.

At the close of these resolutions:

The President.—The Chair desires to remark before adjourning, that we must all regard the days of the Cleveland meeting as red-letter days in our history. (Applause.) I am sure that it is a new departure for the Society. I think we can all congratulate ourselves that we were able to attend the meeting, and I hope we shall make it an example for future meetings.

I have been requested by representatives of various Eastern establishments to ask the members, the Cleveland members and all other members, to be sure and call on them whenever they are in the East, both at our works, offices, and at our various homes, when we shall attempt, in some degree at least—we know that we cannot do it fully—to requite them for their courtesies.

I will say that when it was announced that the meeting would be held in Cleveland, I felt sure from my acquaintance with the local members that it would be a success. But they have gone so far beyond my most sanguine anticipations, that I feel that in addition to the vote of thanks of the Society, I wish to give them my most cordial personal thanks, for it has been a great relief to have everything so pleasant.

Mr. Holloway.—Mr. President, I would like to make an announcement, if it is in order.

The President.—Certainly it is in order. We shall be very glad to hear from Mr. Holloway.

Mr. Holloway.—Mr. Charles Latimer, Chief Engineer of the New York, Pennsylvania & Ohio Railroad, who is, as we Cleveland people know, a very busy gentleman indeed, and who has regretted very much that he has been unable to attend the meetings, and especially regrets that he could not be here to-night, has very kindly sent here some magazines with which he is in some way connected, of which he hopes the members will take a copy. Mr. Latimer has very kindly interested himself, too, in trying to secure for the members of this Association reduced rates of fare to Chicago. He reports that he finds it impossible to do so until next Tuesday. I don't know how you will avail yourselves of them unless you stay till Tuesday, which we shall certainly be very glad to have you do.

There is another feature here which illustrates Mr. Latimer's kindness and forethought. The Road has recently prepared a very elegant map showing the location of coal mines, of the furnaces and of the important stations upon their Road connecting with what is known as the Mahoning Division. Mr. Latimer has very kindly sent here some fifty copies of that map, which he desires to have distributed among members who will be interested in matters of that sort, and at the close of the meeting I shall take great pleasure in distributing them. (Applause.)

The President.—It is very hard for the Chair to ask for a motion to adjourn, after such a pleasant meeting.

Mr. Le Van.—I move we adjourn, Mr. President.

The motion was duly seconded.

After the question was put and carried, Mr. Grant proposed three cheers for the Cleveland members. The three cheers were given with a hearty good-will, and the meeting adjourned.

THE MARINE ENGINES ON THE LAKES, AND A DEVICE FOR GETTING THEM OFF THE DEAD-CENTRES.

BY

J. F. HOLLOWAY, CLEVELAND, O.

THE value of any mechanical device or invention is determined in the end by the necessity there is for its existence. A machine may be very elaborate and ingenious, but if the purpose for which it is created can be accomplished by a simpler and easier method, the complicated machine, no matter how carefully planned, will find no favor.

This being so, it behooves me first to explain the necessity that exists for the device I have to show you, in order that the device itself may find favor in your eyes. The marine engines in use upon the lakes are almost entirely of the inverted direct-acting type—there are, however, a few side-wheel steamers with beam engines still used on the rivers emptying into the lakes, and for short coasting lines. By far the greatest number of these lake engines have single or tandem cylinders connected to a single crank. The next largest number in use are double engines, attached to cranks placed at right angles with each other; while there are a few of the more lately built double engines that have the cranks placed directly opposite each other. While I do not wish to occupy your time in reviewing generally the history of the lake marine engine, it is proper that I should say that it was upon these inland waters that the value of the screw propeller was first recognized as being the best method of propelling vessels by steam. I do not mean that the first propellers used were built here, as they were doubtless first built and used upon the inland canal routes between Philadelphia and New York, but I do mean that while the largest engineering establishments of our country—such as the Allaire, Secor, Novelty, and other large works—were persistently engaged in fitting out ships with beam engines and side-wheels, the engine-builders here in the West were building screw propellers to take the place of the beam engines then in use here. There were even instances where beam engines, that had been superseded here by the more compact and more cheaply run direct-acting propeller

engine, were taken out of vessels and sent East to be used in sea-going steamers!

The early propeller engines were simple high-pressure cylinders, placed on the top of wooden posts, or gallows-frames, which rested upon wooden floor-timbers in the bottom of the hull; and for the class of vessels they were intended to propel, they gave most excellent results. Many an engineer in later times, when he has had an engine hammering and pounding away on iron columns and iron bed-plates, has sighed for the old-time engine with its wooden gallows-frame, and which ran so quietly and so smoothly. The conditions under which the marine engine of to-day has arrived at its present proportions are somewhat peculiar, and may perhaps be of some interest to those not familiar with them.

At the first, the marine engine here was not only simple and non-condensing, but it was small as well. Steam cylinders from 16 to 20 inches bore were the rule. The vessels in which they were used ranged from 275 to 350 tons burden. These small boats, with their small engines, were at that time sufficient to accommodate all the business other than that done in sailing vessels. The growth of the country westward, however, soon gave an impetus to vessel building, and for many years there was a sharp rivalry between larger sailing craft and larger propellers. It is only recently that sail vessels may be said to have yielded to the inevitable, and now, as consorts, or tow-barges, very many of them do their sailing at the end of a tow-line, and the day is past when any large-sized vessel, dependent upon sails alone, will be built upon these inland seas.

The small propellers have in their turn been supplanted by steamers of 270 ft. length, 40 ft. beam, 20 ft. depth of hold, and which rate from 1600 to 2200 tons. The little "Puffing Billy" engines, whose snorting exhaust used to awaken the echoes along the heavily timbered shores of these lakes years ago, have now given place to massive, cumbersome, compound engines, which, in addition to the large and heavily laden hulls within which they are placed, often drag behind them one or more equally large and equally heavily loaded sailing vessels, or tow-barges; and, so far as appearances would indicate, they do it without much effort. Unfortunately for both engine builders, as well as vessel builders, while there has been such a large increase in the size of vessels, and in their engines and boilers, there has not been a corresponding increase in the width, and the capacity of the harbors of the lakes, or in the depth of the water at their entrances, or in the

rivers connecting the chain of lakes together. In consequence of this fact, the large increase in the carrying capacity of the present vessels has been obtained mainly by adding to their length and beam, rather than to the depth of the hold. Since the strength of a hull is largely dependent upon the depth of its sides, and since the overhead arches, formerly used, have been found in late years to interfere with loading iron ore and lumber, the difficulty now is to build a hull that shall be strong enough to carry, in addition to its own cargo, the power required for its own propulsion, as well as the power required to tow one or two vessels of the same tonnage behind it. One of the results of putting such powerful machinery into hulls of this description is that the hull being long and comparatively shallow lacks vertical stiffness. It readily responds to the pulsations of the engine, until, at certain speeds where the number of strokes comes into unison with what might be termed the time of vibration, due to the weakness of the hull, the shaking becomes a very serious matter. While this is true of an engine having a single crank, the use of enignes having double cranks placed at right angles does not in the least help the matter, for not only are cranks so placed much more difficult to balance, but they have in addition to the up and down motion another motion which may be called an *athwartship* motion. When the crank-pin sof such an engine are both on one side of the main shaft, they produce a severe side thrust upon the main journal-bearing, opposite them, which tends to push it sidewise. This side strain, on the return stroke of the piston, is, of course, transferred to the other side of the journal-box, and thus these alternating side thrusts added to and merging into the up and down motions, combine and form a sinuous motion much more destructive to the hull than the simple up and down motion first referred to. Of course these difficulties are increased when the engines are to any extent unbalanced, experience having shown that the better all engines are balanced the less will be their influence upon the hull. The first successful attempt to overcome this vibratory action of the engine upon the hull, was made in the construction of the steamship *Amazon*, which was built in the year 1873. The hull of this vessel was in some respects peculiar: it was 240 ft. long, 40 ft. beam and 20 ft. depth of hold. She was propelled by twin screws, and had two stern-posts, and was built without overhead arches. Each wheel was driven by a pair of fore and aft compound engines, but the cranks, instead of being placed, as usual, at right angles with

each other, were placed so as to bring the crank-pins directly opposite each other. These engines made, ordinarily, 75 revolutions per minute, and so well was the labor divided between the two cylinders, and so carefully had the reciprocating parts of the engine been balanced, that the main shaft, instead of being first pounded down on the bottom of the journal and then against its cap, seemed almost to be suspended in the air. The result was that there were no vibratory motions to be transferred to the hull, and it was almost impossible to tell when standing on the bow of the boat, whether the engines were in motion or not. As a better evidence still of the value of this arrangement of the crank shafts of a marine engine, there is an instance of a large propeller, built recently, which had a pair of fore and aft compound engines, coupled to the main shaft in the usual way by cranks placed at right angles with each other. While the construction of the hull of this propeller differed in no way either as to its shape or strength from boats as usually built, it was so severely shaken by the machinery during the first season it was in commission that it was very evident to the owner as well as the crew that it could not long endure such usage. At the close of navigation, the cranks upon the main shaft were so changed as to bring the crank-pins directly opposite to each other, and the result was that the hull no longer suffered from any motion of the engine. I stated previously that by far the greatest number of engines in use on the lakes had single cranks; and I have tried to show that for large vessels which required double engines, the best method was to place the crank-pins of such engines directly opposite to each other. Now, it will be apparent to all that in at least one particular both the single and the double engines will be alike—they will both have the same liability to "catch on the centre," while being worked slowly, in and out of port.

To those familiar with the narrow rivers and the small and crowded harbors into which, and out of which, these large steamers must so frequently be worked, it is a marvel that much more damage is not daily done. The skill required both in the Master, as well as in the Engineer, of these boats, under such circumstances, could not have been obtained except by long and careful training.

At first, the boats and engines were both small and easily handled; the harbors were comparatively unoccupied, and of bridges there were none.

By degrees the boats increased in size and numbers, and numer-

ous bridges were built over the navigable waters, until now it is a difficult as well as a dangerous task to enter many of the harbors on the lakes. Vessels heavily laden are now obliged to move slowly and with great caution while entering or leaving port, and the frequency with which the engines are made to stop, start, back, or go-ahead, renders them quite liable to "catch on the centre." Owing to the crowded condition of the ports, and the numerous bridges to be passed, if an engine is thus, even for a brief time, disabled, there is great danger lest the vessel shall do or receive serious damage before the engine can be started "off its centre," in the usual way—the usual way being to hunt up an assistant or a fireman, and send him below slowly to pinch over the crank-wheel with a pinch-bar—an operation not only slow, but also dangerous.

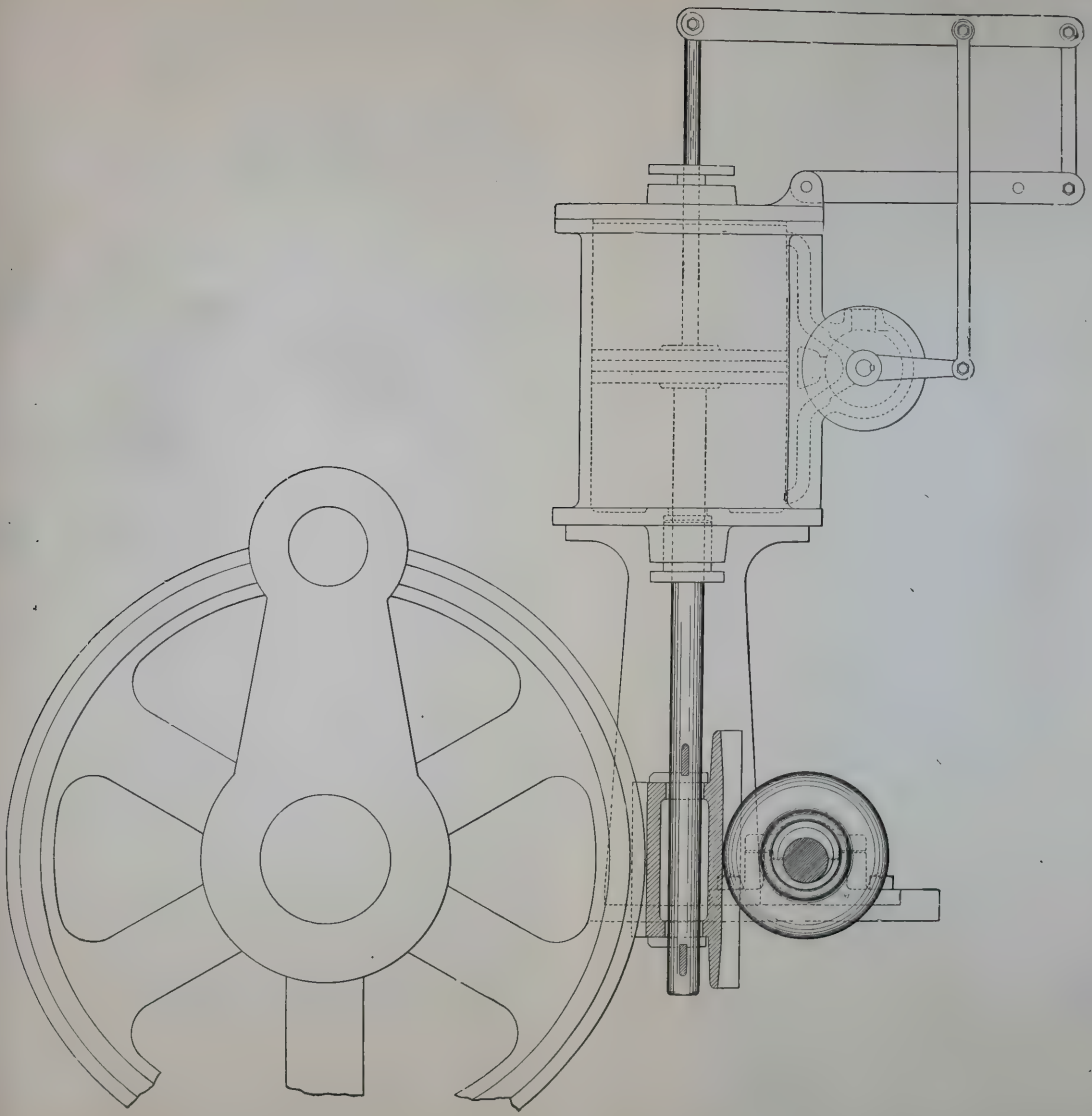
Having, after what has seemed doubtless to you a long time, either skillfully or unskillfully, gotten the marine engine of the lakes upon its centre, my next effort will be to show how best to get it "off the centre," and under weigh again, with the least delay and without danger. The device which I have successfully employed for that purpose, and to which I desire to call your attention, consists of a short-stroke steam cylinder, located in the hold of the vessel, and alongside of the propeller shaft. I place it at the point where the in-board and out-board shafts are coupled together, as the rim of the coupling is very convenient for carrying a portion of the machinery. I place on the coupling flange, or on the shaft, a wheel having on its face a series of V friction grooves. Opposite to this friction wheel, I place either a short segment of a wheel, or a short straight block of iron, which has upon its face a series of V friction grooves corresponding with those on the wheel. This block or segment, as may be most convenient to be used, is connected directly to the piston rod of the short stroke steam cylinder; and it is also so arranged that it may be made to move towards the friction wheel, and to come in close contact with it, by means of an excentric journal, or a similar device.

Now, if in working the main engine forward or back, it becomes caught upon either the upper or lower centre, the valve gear of the engine may be set for turning the engine in the direction wanted, and the throttle-valve may be opened so as to admit steam on the piston if desired. Now, if the block, or segment of the starting engine be brought in close contact with the friction wheel on the propeller shaft, and steam then be admitted to the piston of the starting engine, you will readily understand that the friction

wheel, and the shaft to which it is attached, will be turned a distance equal to the length of the segment or the block. This distance is regulated by the length of stroke of the cylinder of the starting engine, and will be just enough to throw the crank "off the centre."

The main engine will move off at once, having already had its valve gear placed in position, with the throttle-valve open ; while the starting engine has pulled or pushed the segment or block out of gear with the friction wheel, and, of course, out of the way, without any further attention from the engineer. The handles for bringing the block or segment into gear with the friction wheel, as well as the handle for admitting steam to either side of the piston of the starting engine, will both be placed conveniently near to where the engineer stands while working the main engines. He is not obliged to leave his place to work the starting engine.

There are a few other matters of detail which would not be, perhaps, of any particular interest. I may say, however, that the starting engine is designed to work either way, and to turn the engine off either centre. If, when it is required for use, the piston should happen to be at the wrong end of the cylinder, the engineer will move the block or segment back from contact with the friction wheel, will make one stroke of the piston without touching the wheel, and will then move the segment or block back in contact again, when the starting engine will be ready to turn the propeller shaft in the direction wanted. This is done with but a very slight loss of time, and without any necessity for calling upon any one for assistance.



HISTORY AND DEVELOPMENT OF WINDING AND PUMPING MACHINERY IN THE ANTHRACITE COAL REGIONS OF PENNSYLVANIA.

BY

HOWELL GREEN, JEANESVILLE, PA.

THE anthracite coal-beds of Pennsylvania—(some 15 in number), classified by the color of the ash—may be divided into four divisions. The uppermost group is red ash; second, gray ash; third, white ash; and the fourth, or lowest group, is again red ash. This color of the ashes might seem more of a chemical than a mechanical question, but as it is a tolerably sure criterion of the condition of the water in the mine, as well as of the burning properties of the coal, it was early noticed.

These beds of coal lie at every possible inclination to the horizon, dipping under the surface over 2000 feet (say 1000 feet below the level of the sea), and running up mountains hundreds of feet above the beds of adjacent streams.

The first coal was mined where it was most easily got at, so that in the earlier days of the trade (which commenced about 1820), only drifts or tunnels above water-level, and strippings near the surface, were used to get the coal.

Soon the requirements of the market made it necessary to go into the depths of the earth for coal, and means had to be provided to hoist the same, and to keep the mine clear of water.

The soil in the coal regions is poor, and before mining commenced population was sparse, and the few inhabitants combined hunting, fishing, farming, and lumbering in about equal proportions for a livelihood.

On the influx of strangers, who thronged to the newly opened mines, amongst others there came miners and engineers from England, Scotland, Wales, and Germany, who had seen mining machinery and appliances at home; and here in the New World they constructed engines and pumps. Native ingenuity and the absolute necessities of the situation prompted men to plan and build the contrivances to win the coal. Money and enthusiasm lent their powerful aids, and the ever-increasing sum of human knowledge has made

it possible to show, in the last numbers of the series of mining plants, very handsome examples of the mechanical engineering of the anthracite coal regions. The progress is shown in that series from first to last. Some of the early members are yet standing in obedience to the old law of the survival of the fittest; whilst many of them kindly (though sometimes unkindly) have been consigned to the cupola and heating furnace, where have been transmuted so many darling creations.

Very early in the progress of mining below water-level it was seen that means had to be provided to hoist from 300 to 400 feet at one lift, so as to get space for breasts, to work the coal profitably; and the quantity of water to be raised was found to run into hundreds of gallons per minute. From the first, both slopes and shafts were used. The mine cars in the anthracite regions have always been large, starting in the early days at about 40 cubic feet capacity, and standing now at about 96 feet. The wheels of the cars have been from 12 to 20 inches diameter; 18 inches is now most generally used. The axles have been from 2 to $2\frac{3}{4}$ inches diameter. The gauge of the mine railroads varies from 30 inches to 48 inches; in a few cases it is 4 feet $8\frac{1}{2}$ inches. At first chains were used for hoisting, and some of the early shafts had hemp ropes. Flat chains, or, rather, three chains side by side, with alternate large and small links, and with blocks of wood through the large link, were tried. These flat chains were wound on flanged spools like a ribbon. Iron and steel bands were used, but the conclusion of the greatest number now is to use iron-wire round ropes. Not that iron-wire ropes are better than steel-wire ropes; but questions of endurance, cost, etc., in relation to wear and weight and work in acid water, have rather been against steel-wire ropes. In a shaft no rope rollers are used, but on a slope—particularly one with varying pitches—the question of a roller to protect the rope is most important. While it has been a vexed question, yet after trial of hundreds of forms and many kinds of material, it seems to be considered that a hardwood roller about 8 inches diameter, truly turned, and kept clean and clear, is the best for ordinary strains. It was soon found out, in using wire ropes, that the life of the rope was much lengthened by making the drums and sheaves of large diameter—the rope must spring around the drums and sheaves, and spring back, and not receive a permanent set.

The first steam engines used for hoisting anthracite coal and pumping the water (and at first they combined both duties) were

single high-pressure engines, with flat bed-plates bolted on wood frames. The steam cylinder would be perhaps 18 inches diameter, with 6 feet stroke. A cast-iron crank-shaft, with perhaps a 10-inch journal, carried the heavy fly-wheel. On the crank-shaft there was a pinion 30 inches diameter, of 3 inches pitch and 12 inches face, which geared into a drum wheel 60 inches diameter, which was just above the pinion. Just under the pinion was the pumping wheel, 8 feet diameter; this pumping wheel had holes in it to receive a pin for working the pump. The drum shaft was of cast-iron, with perhaps an 8-inch journal; its body, as that of most all other shafts then, was octagonal, and the drum-wheel spiders and most everything else were staked and keyed on by the methods of the old millwrights. The drum was from 5 to 8 feet diameter, and about 11 feet long, and was formed of hardwood laggings bolted on spiders. To wind a car 400 feet with a 5-foot drum, the engine would have to make about 48 revolutions, which it was made to do in about one minute. The pumping shaft was also of cast-iron, with perhaps 11-inch journals; and the drum shaft was lifted in and out of gear by a strong wooden lever, one of the pillow blocks being hinged for that purpose. The pump was, of course, near the bottom of the mine, perhaps 400 feet away. It was a lifting pump, 16 inches bore, 7 feet stroke, fitted with a bucket faced with sole leather, the rod of which went through a stuffing-box in a goose-neck, or turn-piece. Up the slope or shaft went a wooden rod, 8 inches square, carried on flanged rollers. The rod was spliced with plates $4'' \times \frac{5}{8}'' \times 10$ feet, and on top of the slope or shaft were one or more rocking bobs, provided with great balance boxes.

The rods connecting the balance bobs to the wheel were $8'' \times 16''$, and were provided with suitable straps, etc.

The valve gear of this engine consisted of two eccentrics and rods with hooks on the ends, which the engine man lifted in and out of gear with his feet, thus leaving his hands free for full control of the slide-valve, which he operated with a long bar. He regulated the quantity of steam for the engine by a throttle of the stovepipe-damper pattern. Thirty years ago such a pumping and hoisting engine was considered first-class, and many of the old fellows are yet at work.

Such an apparatus was subject to many mishaps. With a heavy fly-wheel whirling around, and the slide-valve at the will of the engine man, unnecessary strain could be easily thrown against the engine, and broken cranks and shafts were often the consequence.

Also, if in lifting the drum out of gear it was not securely scotched, the unbalanced end of the chain would fly down the slope or shaft. When it was necessary to connect or disconnect the pump rods, the rocking bobs had to be securely blocked, and sometimes the assistant forgot to take out the last block—and then trouble came.

This state of affairs was much improved by putting up another engine, so that one engine could pump, and the other one could hoist. Next it was discovered that two engines could be attached to the same shaft, at right angles to each other, so that no fly-wheel would be wanted. Yet on some of the first pairs so built, small fly-wheels were put on—probably to verify Darwin's theory of gradual development. The first of these double engines had two eccentric hooks to each engine, making four in all, which the engine man had to lift withlevers. Now he had two engines to handle, and it took a lively man to do it; but since there was little or no fly-wheel, no great danger was incurred. The engine man, therefore, hooked one engine in and started the load with the free engine. These double engines with four hooks did very well. Next, links for valves were introduced, and they are now generally used.

It was found that hoisting and pumping engines in which cog-wheels were used were subject to noise and break-downs, and as the mines went deeper it was found that drums keyed immediately on the crank-shaft of a double engine did the best. This change, of course, involved larger steam cylinders, and in the place of wood-faced drums cast-iron ones were made, which soon led to the use of spiral grooves to keep the ropes from chafing. Still further, these drums were made conical, so that when the heavy load was to be started the small end of the cone did the pulling, whilst the empty car (and cage, if in a shaft) pulled by the large end of the cone on the other side. This arrangement is the best yet tried—and so the hoisting engines stand to-day. These are strongly built double engines on strong stone foundations, with steam cylinders from 20 to 40 inches diameter and stroke from 4 to 6 feet. There are heavy wrought-iron shafts, spiral-grooved cast-iron conical drums, steam brakes and steam reversing gear, with apeliances to prevent over-winding, with safety catches and detaching gear; and, barring waste of steam, the world can show no better hoisting engines than are in the anthracite coal regions of Pennsylvania.

To a mine below water level, the pump, or other appliance to raise water, is of first importance. When man enters nature's great

storehouses in search of wealth, he finds that water is ever ready to dispute his supremacy. Sometimes it is the constant stream, only varying with the season; often there are great quantities stored in the crevices of the rocks. In parts of the anthracite coal regions, the fact has been shown that the first 100 yards down the vein has the most water; the next 100 yards has less, and after that the vein is often perfectly dry. Perhaps the most discouraging situation for a mechanical engineer to be called to in the anthracite coal regions, is to have to provide the remedy for an old drowning mine, where the vein is large, the pitch steep, the top bad, the mine full of fire-damp, the timbers old and rotten, and the water so full of acid that it will eat up a shovel in a night, with the air so close that one can hardly breathe. On these occasions darkness and danger are our companions, and great expense and long delay are our inevitable followers.

The first mining pumps used were of the Cornish pattern—the old drawing lift with an iron bucket faced with leather. This leather was held in place by a wrought-iron or brass ring which nearly fitted the working barrel, and was driven full of wooden pegs. If the working barrel was made of hard iron, and the length of the rod nicely adjusted, so that the leather would come slightly above the bore in the up stroke, and if the water was clean and not acid, and the lift not too heavy—then, this is still the best mining pump ever made. The red ash veins were the first ones worked below water level, and the water in red ash mines will not, as a rule, eat up iron; but when slopes and shafts had to be sunk on the white ash veins, there the lifting pumps would not do. The sulphuric acid in the water ate them up. Some brass working barrels and brass rods were tried, but they were expensive and short-lived. Open-topped force pumps were made, hoping that they could be lubricated and made to stand, but the general conclusion arrived at, about the year 1848, was, that plunger pumps must be tried. Since that time they have been generally used, and the reason of their longer life is that plungers can be lubricated and the corroding action of the acid water lessened. As the first lifting pumps were worked by rods running up to the engine, quite a change in balance boxes occurred when lifting pumps were changed to plungers, and about this time quite a number of double-acting pumps were put in. These pumps, of course, discharged water at each pass of the piston, and had four valves instead of two. About the year 1854 or '55, the Bull engine and pump were introduced.

These did away with cog-wheels for pumping, as the pump rods were fastened to the piston rod of the steam engine. No fly-wheel or crank was necessary on these engines, since the cylinder was made large enough to lift the rods which were made heavy enough to force up the water on their downward stroke.

These engines and pumps have been a real success. They had to be very strong, from the nature of the case. The valve gear is beautiful. It is the result of one hundred years' experience in Cornwall, from whence the idea came. The engine man has to be a man of good judgment, as he deals with very heavy weights. Yet, as regards consumption of steam, the two-valved engine of the anthracite coal region compares very unfavorably with the three-valved Bull engines of Cornwall.

About the year 1860, steam pumps began to be used in the coal mines. The great departure was in bringing the engine and pump together; and from the unfortunate nature of the case, the engine had to be taken down in the mine 500 to 1,000 feet from the boilers. Here commenced another trouble, which is the great loss of the power of the steam so conveyed.

Strange as it may seem, the old war between acid water and pistons and rods had to be fought over again, and the acid water came out ahead with steam pumps, just as it did with lifting pumps.

This paper must be too short to go over all the questions of steam pumps, with their valve movements—positive, isochronal, and steam-moved,—of pumps alternate and reciprocating, with bronze linings, rods and valves; with roomy valve-chambers and easily changed seatings, etc., with air chambers and air lodgments; together with questions of relative size, speed, and portability. Yet I must take time to say, that to pump acid water a plunger seems the best, because it can be protected by grease (in cold water), and the action of a piston on the lining of a pump will even hasten the corroding action of the acid water; that steam carried 500 to 1,000 feet, in pipes ever so well covered, will lose much of its power; that ordinary high pressure steam engines, using such steam and making no use of the principles of expansion, are great wasters of steam; that centrifugal pumps, even with short lifts, will hardly do for acid water; that the introduction of steam into vessels just emptied of cold water seems a return to the days before James Watt; that the ponderous engines of Cornwall, or the splendid examples lately set up at our American water-works, are too costly

for the ever-changing locations incident to anthracite coal mining; and that while, to men who daily see hundreds of tons of good culm thrown away, small savings of steam seem foolishness; yet in view of the great fact that in the best steam pumps in the coal regions the fuel used is four times as much as it might be, there seems room for improvement on that score. As the pumps now stand in the anthracite coal region, those which use the least fuel are the old plungers, worked by engines on the surface, using cog-wheels and pinions. Next in point of economy are the Bull pumps. Then follow various kinds of steam pumps—good, bad, and indifferent. None use the principle of expansion to a very great degree, and the duty done by 100 lbs. of coal may be stated at from 10,000,000 to 20,000,000 pounds of water raised one foot high.

The pumping of the water of the anthracite mines is an ever-increasing trouble. The mine widens, the out crops fall in, and as the quantity of coal to be had decreases, the water increases. For this state of affairs there is no help. Some collieries in the middle coal-field use, at certain seasons of the year, one hundred tons of coal per day for pumping water, to raise 8,000,000 of gallons in twenty-four hours, from a depth of four hundred feet. When wet seasons come on, the water in the mines gets more troublesome on account of acid which is extracted from the rubbish left in the mine. The water of the mines is not good for use for purposes of condensation, because, when heated to one hundred degrees, it acts on iron with increased force. Fresh water gets more and more scarce, and water is brought long distances by pipes, and often in cars, to supply the boilers; and in some districts good artesian wells are bored. Here, however, another trouble comes in: if the holes go down too deep, the mountain limestone is reached, and lime is more troublesome than sulphuric acid. But by mixing the two together, under intelligent care, a good water is obtained.

And so the situation is. The question that to-day troubles the minds of many engineers in the coal regions is, How had we best build our mine pumps—shall we stick to the old method of a plain steam pump, with no expansion or condensation, because it is so handy to put in and take out? So far as the pump alone is concerned, the answer seems, Yes; but when we see the long row of boilers, and immense piles of fuel for them, it calls attention to the other side of the question. If by this imperfect sketch, the writer shall have called the attention of this Society to this difficult and important question, he will be satisfied.

ON A NEWLY DISCOVERED VARIATION IN THE EFFECT OF PROLONGED STRESS ON IRON.

BY

ROBERT H. THURSTON, STEVENS INSTITUTE OF TECHNOLOGY, HOBOKEN, N. J.

Early in the year 1874 the writer presented to the American Society of Civil Engineers a paper on "The Strength, etc., of Materials, as exhibited by a testing machine having an autographic registry," in which paper some singular and important effects of prolonged and intermitted stress were described for the first time. In considering the effect of time of application of stress, it was shown that a peculiar difference of effect was observable in metals accordingly as they belonged to the viscous or to the non-viscous classes, or, as the writer then stated it, to the iron or the tin class.

It was shown that soft metals are subject to a flow which causes gradual yielding under their maximum loads, while common iron and steel, on the contrary, exhibit a singular elevation of the normal limit of elasticity when subjected to intermitted stress. It was further remarked that the well-known experiment of Vicat *—in which he found that iron wire loaded with two-thirds its breaking weight, as determined by ordinary test, gradually yielded and finally broke, after two years under stress—were indications of the probability that this process of stiffening under load may, nevertheless, be accompanied by a flow causing ultimate fracture, if the load be heavy. No evidence of such flow had, however, been detected by the writer in ordinary iron, although occurring almost invariably with other metals.

It was finally concluded to repeat the experiment of Vicat in as nearly as possible the same way as the original tests were made.

Two samples of wire made by the Trenton Wire Works were furnished the writer by Mr. Wm. Hewitt, the Vice-President. Both were No. 36 wire (B. W. G.), 0.004 inch (0.1016 mm.) in diameter, and of the same kind of iron. One coil was hard-drawn, directly from the plates, and the other was very thoroughly annealed,

* *Annales de Chimie et de Physique*, 1834.

and, consequently, soft. Lengths of each kind of wire were carefully tested in the usual manner, to determine their strength under ordinary conditions of test, and similar lengths were then measured off for test by prolonged stress.

These latter specimens were suspended from a set of coiled springs hung from the ceiling in the study of the writer, where they would be constantly under his eye, and where, also, they would be safe against accidental injury. These springs were used because it was found that the jar due to the breaking of one wire was liable to injure those hanging near it.

After the wires were suspended they were carefully loaded, and were finally thoroughly painted with oil-paint, and left, carrying weights as below.

The table gives the weights in percentage of maximum loads under test, in the testing machine, in the usual way:

EFFECT OF PROLONGED STRESS—SWEDISH IRON WIRE.

Per Cent. Max. Static Load.	Time under Stress.	
	Hard Wire (Unannealed).	Soft (Annealed).
95	80 days	3 minutes.
90	35 "	5 "
85	18 months, still unbroken.	1 day.
80	3 "	9 months.
75		17 days.
70		15 months.
65	Unbroken.	" "
60		Unbroken.
55		"

These figures seem to reveal an important difference—previously undiscovered, so far as the writer is aware—between hard and annealed iron wire. Hard wire, unannealed and just as it left the draw-plate, sustained 85 per cent. its original breaking load, as determined by usual tests, eighteen months; and a wire loaded with 5 per cent. less weight, 3 months (the difference is probably due to some concealed defect in the latter), while the same wire, annealed and thus softened so much as to have carried about half as great a maximum load, broke under but 65 per cent. of that reduced load at the end of 15 months.

Those wires which are still unbroken will be left suspended, and, meantime, another series will be put under test. The final result will be reported to the Society in due time, should they all finally

break. The broken wires exhibit no traces of corrosion or injury, and the coat of paint with which they are covered is apparently as sound as when first applied.

These results evidently more than corroborate the experiments of Vicat, showing progressive disruption in both qualities of wire when heavily loaded. They also exhibit an unsuspected difference in the degree to which this occurs with hard and soft iron, showing the former to be, apparently, the safer. It is interesting to observe that the factor of safety for soft iron, under prolonged stress, must be as great as that for timber under the same conditions, both remaining uninjured by oxidation. These new facts have seemed to the writer so important that he has already announced the conclusion here given by publication in "Science." They are presented here also as being of especial importance to the engineer.

A NEW FORM OF BALANCE DYNAMOMETER.

BY

S. S. AND W. O. WEBBER, LAWRENCE, MASS.

THE Balance Dynamometer, represented by the accompanying drawings, was originally invented by Mr. Samuel Batchelder, then agent of the York Manufacturing Co., at Saco, Maine, in 1836.

The principle of the instrument is, that to hold a weight by the radius of a circle, in a horizontal position, at a constant distance from its center, takes as much power as to lift the same weight through the distance which would be traversed by it in any given number of revolutions around said centre or axis, and in the time required for such number of revolutions.

Thus, in the present instance, the scale-beam or steelyard is the radius of a circle, of which the circumference is ten feet, and the pin on which the weight is suspended would therefore traverse a distance of 1,000 feet in one hundred revolutions.

Now, one pound lifted 1,000 feet is equal to 1,000 pounds lifted one foot, and the weights used on the dynamometer are numbered accordingly.

Following out the operation of the machine, we will suppose that twelve pounds are held up on the scale-beam, and that the counter shows a speed of one hundred revolutions in six seconds, a worm and gear being arranged so as to ring a gong-bell at every one hundred revolutions of the shafts.

The twelve pounds, which are called 12,000 pounds, are then divided by the number of seconds consumed in the one hundred revolutions, and the result is $\frac{12000}{6} = 2{,}000$ pounds lifted one foot in a second, which result being divided again by 550, the equivalent expression for a horse power in feet per second, gives 3636 H.P. as the load passing through the machine.

The operation of the dynamometer is this: on the receiving shaft, in the present arrangement, are fixed a pair of fast and loose pulleys at one end, and a spur gear at the other. This spur gear drives a corresponding gear of the same size and number of teeth, which is fixed on the end of a sleeve or collar, having on its other end a bevel gear, which forms one side of what is known as a

"box" or "compound" gear. A corresponding gear on the opposite side of the "box" is fixed on the delivering shaft, which passes through the sleeve above mentioned, and also through the fulcrum of the scale-beam. The two remaining sides of the "box" are composed of a pair of equal and similar gears, which revolve freely around the scale-beam on either side of the fulcrum. One would really be sufficient for the purpose, but a pair is used in order to preserve a balance.

When motion is given to the shafts by means of a belt to the receiving pulley, the intermediate gears revolve about the scale-beam without effect; but when a belt is carried from the delivering pulley to the machine to be tested, the resistance causes the intermediates to act with the effect of levers on the scale-beam, and would put the latter in revolution about its axis or fulcrum, if it were not restrained by the weights, which are to be added and adjusted until a balance has been obtained.

It will be readily seen that the real motion of the scale-beam, were it free to move, would only be one-half that of the shafts, and the weights in actual use are therefore double their apparent value, or, in other words, the weight marked 1,000 pounds is in reality two pounds instead of one.

In the original machine as invented by Mr. Batchelder, only one shaft was used, on which a pair of pulleys was put on one end, and another pair on the sleeves, at the other, carrying the bevel. But this arrangement required a change either in the position of the machine to be weighed, or its driving pulleys, for every test, and a second shaft was added by Mr. Jas. B. Francis, of Lowell, in order to bring the receiving and delivering pulleys into the same driving plane, and a further addition was made by him, at the suggestion of the late Uriah E. Boyden, of the dash-pot, or hydraulic regulator. This is a cylinder filled with water or oil, in which a piston traversed with moderate freedom, and which is attached to the other end of the scale-beam in order to check vibrations and insure steadiness.

In the first machine built for Mr. Francis, and in several others either copied directly from it or slightly varied, the two shafts were upon the same horizontal plane, and increased the length of the floor space required, so that in many cases it was difficult to place the dynamometer in the ordinary alleys or floor space left between the machines in the cotton or woolen mills or machine shops.

This difficulty is obviated in the form of construction adopted

in the drawings by placing the shafts vertically, one above the other, and space is also economized farther by making the frame of iron, instead of wood.

The diameter of the dash-pot or hydraulic regulator is increased so as to obtain a more perfect resistance to vibratory or irregular motion, while the piston has sufficient clearance to move freely through the oil, which is used as a resisting fluid, at a slow velocity.

The bevel gears are of cast-steel. The central hub or fulcrum of the scale-beam, around which the intermediate gears revolve, and through which the shaft passes, is of phosphor-bronze, to ensure the necessary strength with the least friction.

A pair of pullies is provided for each shaft, the inner one of each pair being keyed fast to the shaft, while the outer ones are fitted with set screws, having proper seats sunk in the shafts, so that they can be locked, so as to make one wide driving pulley; or, by releasing the set screw, they can be made into a pair of fast and loose pullies, for the receiving shaft, according to the direction from which the belt is delivered, whether from above or below.

The gear teeth have been made of ample strength to resist the pressure of all the weights furnished with the instrument, if the whole strain were applied to one tooth, and as they are so cut that three teeth will always be in contact at the same time, the factor of safety is amply sufficient, and the power which can be weighed, by the use of all the weights, is equal to one horse-power for every hundred revolutions of the shafts, or to all the power which can be relied upon to be transmitted with safety by a single belt of $2\frac{1}{2}$, or even 3 inches wide, although the pulleys are intended in the machine which we have built for a belt of $2\frac{1}{2}$ inches.

The scale beams are made detachable for convenience in packing and transportation, and a "guide-wire," or "sight-rod," is added fitting into a socket in the frame, and standing, when level, parallel with the steelyard, by which the operator can easily see when he has attained his balance.

The floor space occupied by this instrument is 30x24 inches, and its weight for the machine alone is 284 pounds, the weights for use, which accompany it, being seventy pounds in addition. It will thus be seen that the Dynamometer as constructed gives the minimum of weight and space occupied for its capacity, and is easily adjusted in position and requires no change to be made in the position of the pulleys on the machine or shaft to be tested.

All that is necessary is to locate the Dynamometer in position to belt from the line shaft and on to the machine which is to be tested, to fasten the legs with four lag screws to the floor and to attach the belts—all of which is done in a short time. In every case the running balance of the Dynamometer when belted should be weighed before throwing off the belts after the completion of any test, and this balance weight deducted from the gross gives the net power consumed in the machine so tested. There has been exception taken by some engineers and others to the results obtained by Dynamometers, and in many instances there was good reason for so doing. Any form of Dynamometer depending on springs, actuated by centrifugal forces or otherwise, must in time become inaccurate, if not so when first constructed. The form described is thought to be the true one ; and since it embodies the principle of a known weight actually lifted through a known space, it must be very accurate. As proof of this, it may be said that such a machine has been used for the past ten years, weighing over one hundred thousand H.P., in small amounts, and the totals, in some cases aggregating 250 H.P. have agreed within a few per cent. with the results obtained from indicator-cards taken from the engine driving the same machinery. In addition, numerous comparative tests, made with the Prony brake, all showed that the error, if any, was extremely small between the two, provided, of course, that the test were accurately made and with proper apparatus for a Prony brake. In these days, when economy of power is becoming such a study, a reliable instrument, easily applied, will be found an invaluable aid to engineers and others with whom the supplying or use of power is a source of profit.

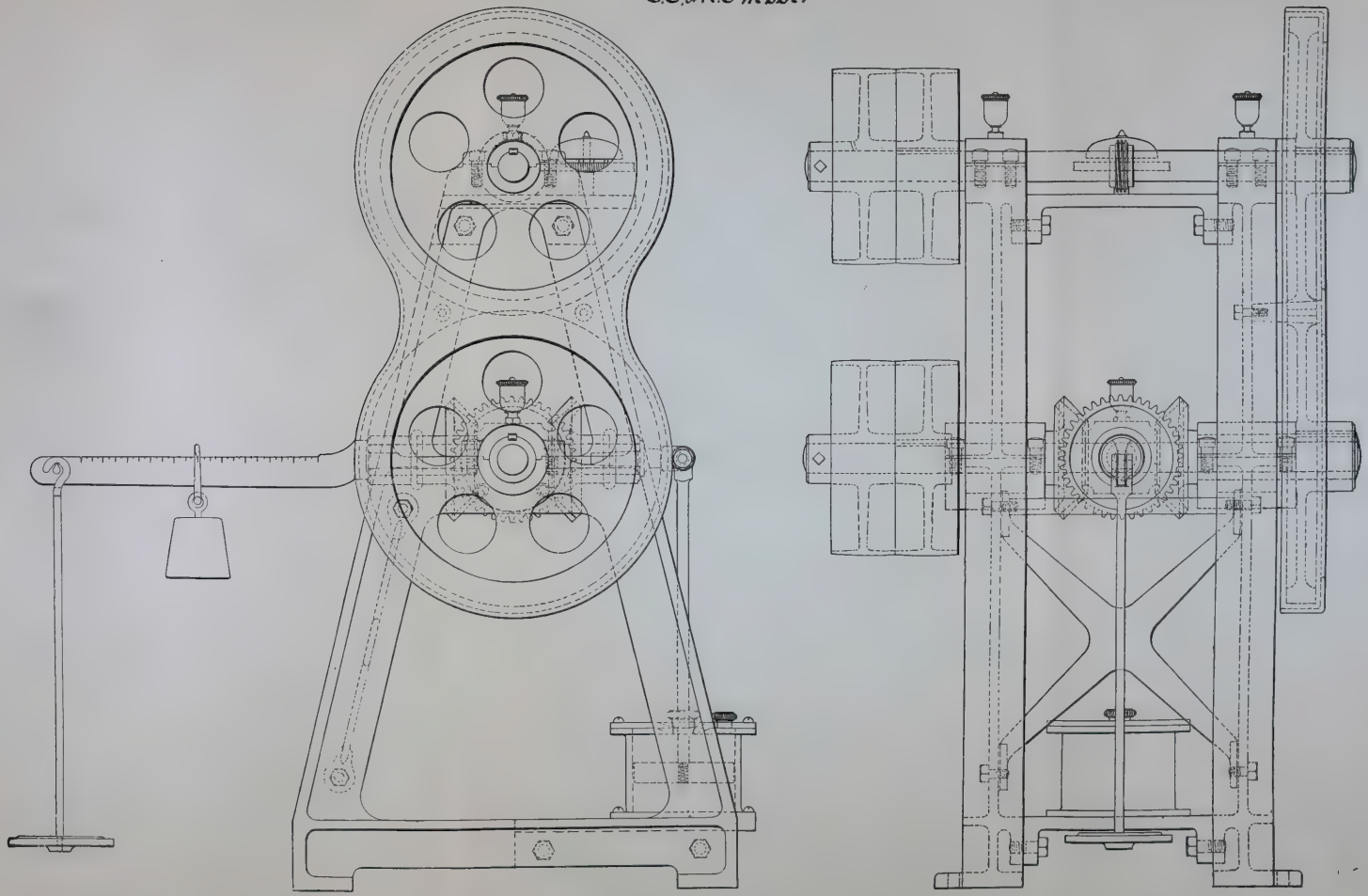
10 H.P. Balance Dynamometer.

Built by

Lawrence Machine Shop

Lawrence Mass 1883

S.S. & W.O. Webber



A NEW METHOD OF CONSTRUCTING A CRANK SHAFT.

BY

JOHN E. SWEET, SYRACUSE, NEW YORK.

In making a pair of steel crank shafts larger than could be managed by the tools in the shop, if handled in the ordinary way, recourse was had to unusual means, and with so satisfactory results that it is hoped that a brief description will prove interesting and, to some extent, useful.

The crank disks, some 10 inches thick and 44 inches in diameter, had to have 10-inch holes for the shafts and 7-inch crank holes bored 15 inches between centres. To do this on a lathe in the usual way required a lathe of 6 feet 2 inches swing, and the unsatisfactory operation of moving and resetting each piece of a ton and a half's weight.

For use in ordinary work in the shop is a boring bar mounted on the carriage of the lathe, the axis of which is 9 inches below the centre of the lathe spindle. This boring bar is rotated by independent belt power, and the feed of the lathe is arranged to run independent of the lathe spindle, so that a piece fastened to the face plate of the lathe may have the holes bored in it when brought into the correct position. The trick was so to locate the disk on the face plate that both holes could be bored by simply rotating the face plate from one to the other. Fig. 1 shows the position when the shaft holes were bored, with the dotted lines showing position when boring the crank holes. The crank pin holes were bored 7 inches, and the pins, which were of tool steel, turned $7\frac{1}{1000}$ inches their entire length. Then the part that was to form the wearing surface was ground and polished to 7 inches, and the pins forced into the disks from the back, the finished portion serving as a guide to insure a fair start.

Next, so much of the rough shafts as was to fit the crank disks was turned and key-seated and the shafts forced in. For this an allowance was made of $\frac{1}{1000}$th of an inch, and is believed to be sufficient, since it required, as near as could be determined, about 90 tons pressure to force them in. To insure the shafts being truly parallel with

the crank, a cast-iron chuck, as shown at Fig. 2, was prepared to go over the out-board end of the shaft provided with four heavy set screws, and a $1\frac{1}{2}$ inch reamed hole in the centre. In this hole was put a female centre, the rig forming an adjustable centre by which the out-board end of the shaft could be moved in either direction. With the shaft in the lathe, and one of Mr. Porter's V pieces and a sensitive level, it was possible to get the parallelism perfect. Removing the female centre from the chuck and putting in bushings to fit the centre drill and counter-sink, new centres were made in the shafts and the work finished eminently satisfactorily. So perfect had our method of boring the holes in the cranks proved that the final error did not exceed $\frac{1}{50}$th of an inch in the length of the 10-feet shafts.

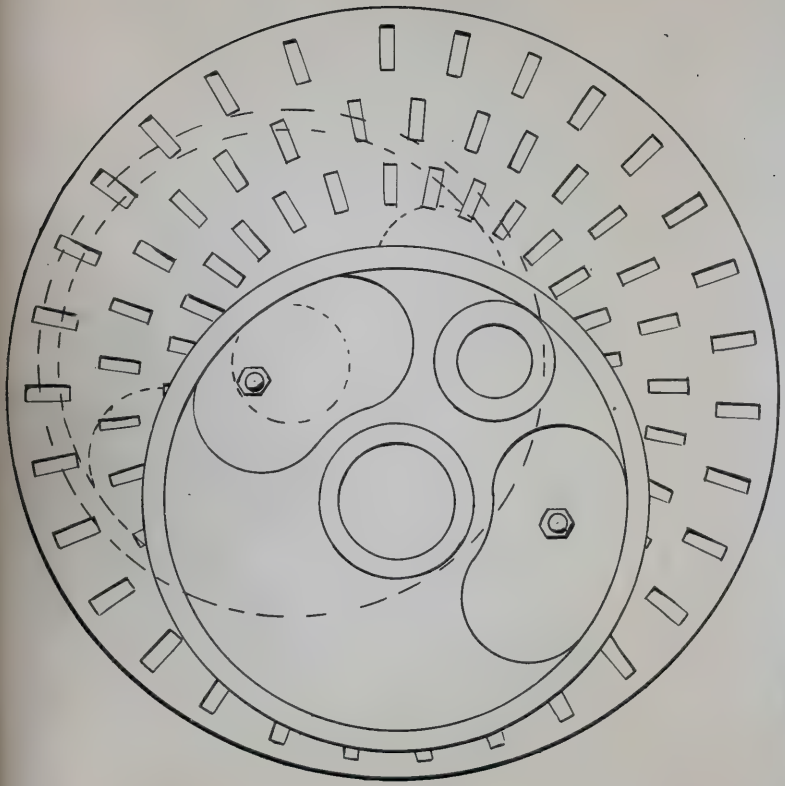


FIG. 1.

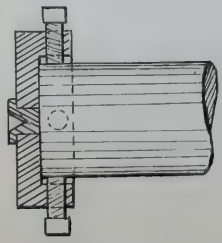


FIG. 2.

ECONOMY BY SUBDIVISION IN INSTALLATION AND OPERATION OF POWER AND MACHINERY UNDER VARYING DEMAND.

BY

JULIUS L. HORNIG, JERSEY CITY, N. J.

THE question of economy in the construction of steam engines or motors has been discussed with great ability and science, so that the importance of the subject is generally appreciated and a selection is made from the most approved constructions. The economy by suitable adaptation and installation is a question which requires the same attention.

This article is intended to treat, in general, of the propriety of subdivision in installation where varying service is required. Such cases arise in central stations for supply of power, water, light, etc., or in manufactories, where a number of tools or machines are consuming power at varying demand. The object of the writer is to lead to further discussion and elaboration.

The generators of steam, for power under varying demand, will show higher economy by suitable subdivision. The fact that the highest economy in steam generation takes place when the most perfect combustion takes place, indicates that the temperature of the fire should be kept nearest to this point. Therefore, a variation in the quantity of steam required demands that a variation in grate surface should take place, or, in other words, that more or fewer boilers should be operated accordingly.

The question of combination of smaller and larger boilers is worthy of investigation; and, also, the subject of loss of heat from boilers while the fire is banked, in comparison with the loss of heat from boilers at low temperature of fuel and losses consequent to that.

Steam engines, built for certain maximum capacity, will naturally show at full service the highest economy. Their loss by friction, inclusive of connections or transmissions to do work at a fixed speed, will be found essentially the same from minimum of work to their full capacity.

When work varies much, as, for instance, in the supply of light, this investigation proves important.

The attached economy-curves are worked out approximately from several systems of indicator-cards, and furnish the following:

Comparison Table of Useful Percentage up to Full Capacity.

Work-Divisions.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10th.
Per cent. for large Machine ..	35	55	66	75	80	86	92	95	98	100
Per cent. for small Machine..	55	75	86	95	100					
Per cent. difference....	20	20	20	20	20					

The small machine, which has only half the capacity of the large one, doing the same work as the large machine, shows a gain of 20 per cent. if used instead of the large machine when the latter is worked only to half of its capacity.

To consider the loss, a few comparisons only may serve here. In assuming a number of the same class and size of machines installed, and referring to the curve of large machine, the per cent. of loss will be found:

Working 2 machines, $\frac{1}{2}$ capacity, in place of 1 full = 20.
" 3 " $\frac{2}{3}$ " " 2 " = 10.
" 4 " $\frac{3}{4}$ " " 3 " = 7.
" 5 " $\frac{4}{5}$ " " 4 " = 5.

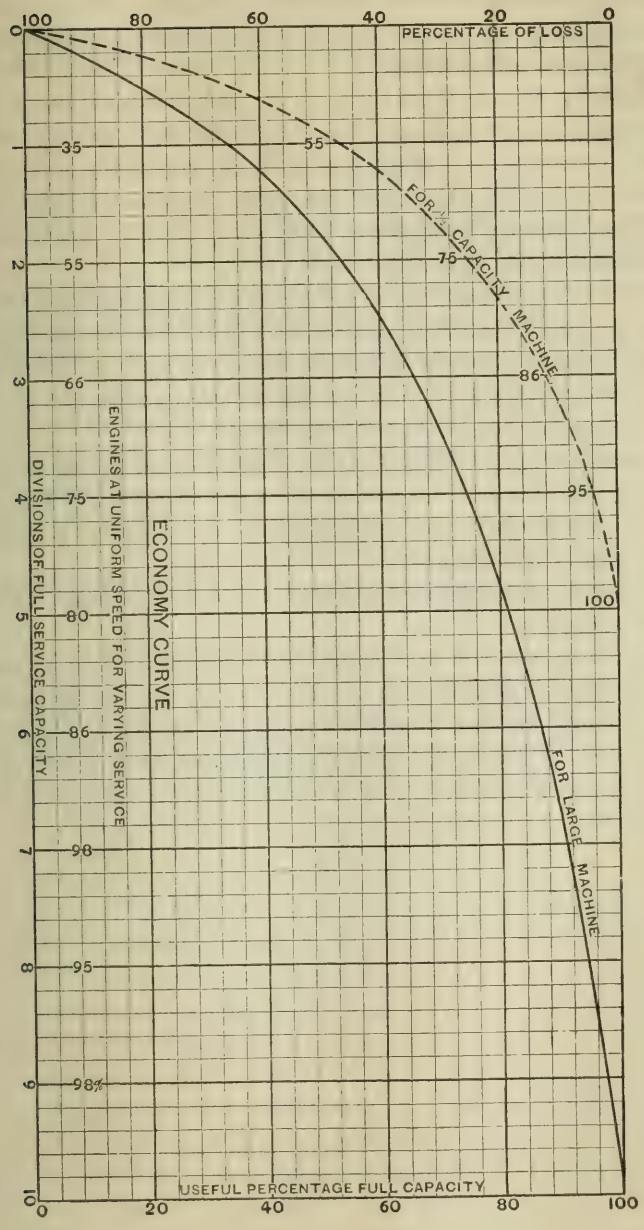
The curve shows a loss of:

20 per cent. for using a machine only $\frac{1}{2}$ capacity.
34 " " " " " $\frac{3}{10}$ "
54 " " " " " $\frac{3}{20}$ "

The combination of working machines of different capacity must be, evidently, advantageous, when using the smaller only for work up to its full capacity, then to change the work on to the larger up to its full capacity, laying the smaller up during the intermediate higher range, and add its service only at demand of rate above capacity of larger machine.

This combining of machines to keep their service nearest to their full capacity must secure the highest economy.

The rate of friction in steam engine and transmission in other installations will not vary much from electric light machinery taken here as sample, and therefore a similar importance must exist.


PERCENTAGE OF LOSS
100
80
60
40
20
0
35
55
75
86
95
100
FOR ½ CAPACITY MACHINE
FOR LARGE MACHINE
ECONOMY CURVE
ENGINES AT UNIFORM SPEED FOR VARYING SERVICE
DIVISIONS OF FULL SERVICE CAPACITY
USEFUL PERCENTAGE FULL CAPACITY
0
20
40
60
80
100
1
2
3
4
5
6
7
8
9
10
55
66
75
80
86
90
95
98%

This question of economy will apply to the installation of a number of pumps driven by a number of engines, where the service varies at times; also to a series of tools or machines operated under varying demand at factories.

The Holly Water Works Co. carry out a combination of several steam engines operating one main shaft and make steam connection to their cylinders, so that some or all may be used for high pressure, or some as second expansion cylinders, as demand may require. This should meet the requirement of subdivision in installation for economical service very effectively.

In first installations frequently the engines are adopted largely in excess of present service required, as a provision for future extensions, whereby losses are caused in the meantime by increased friction, by the necessity of carrying low steam pressure and by irregularity in motion due to injudicious expansion.

In transportation service the timely addition of the so-called hill-horse for vehicles and the pusher for railroad trains, at the steeper parts of the roads, is an established mode of working motors to nearest steady full capacity.

The auxiliary boilers and engines are found in large works for similar assistance.

From boiler tests on best constructed boilers it is to be assumed that the highest economy is reached by consuming $9\frac{1}{2}$ pounds of anthracite egg coal per hour per square foot of grate, producing 3_1 horsepower. This would give the ratio for best subdivision of boilers to suit a subdivision of engines in installation.

A NEW METHOD OF CASTING FLANGE PIPE.

BY

JOHN E. SWEET, SYRACUSE, NEW YORK.

Edison says "he attributes a large part of his success as an inventor to the fact that he knows so many things that won't work"; and again, that "he does not think he can make many more mistakes, as he must have made them about all already."

Our experience in attempting to cast flange pipe so they should come out of the sand complete has often reminded me of Edison's remarks, for I now know lots of things that won't work, while the number of mistakes appears to have reached about 95 out of a possible hundred.

Having too much foundry an order was accepted for a lot of flange pipe, and having too small facilities for facing and drilling the attempt was made to cast the ends faced true and the bolt holes cored.

The plan consists in casting the ends of the pipe against a chill, and the arrangement is shown in the figures. Fig. 1 shows the pattern, which differs from the ordinary pipe pattern in having movable flanges to suit different lengths of pipe, and in having the core prints the full size of the flanges instead of the size of the bore.

The flask, Fig. 2, is of the ordinary iron sort, having ends adjustable at intervals of a couple of inches, and with openings in the ends equal to the size of the core prints.

The core bar, Fig. 3, is an inch or two smaller than the pipe, having circular flanges an inch and a half or two inches apart and four ribs throughout its entire length.

The core bar has the ribs turned true and to a given size, upon which is fitted two chills shown as AA.

The chills may be set in any position to suit the length of pipe required. The faces are recessed so as to form a facing for the packing on the finished pipe; and as many holes as there are to be bolt-holes in the flange are bored completely through the chill, accurately spaced and reamed slightly tapering.

The outsides of the chills are turned to the same size as the prints on the pattern, except that there is left on the outside a small sharp

projection about $\frac{1}{8}$ inch high—and this is the sharpest dodge in the whole scheme.

The chills when on the bar form journals, so that when rested in proper bearings the core bar may be rotated. Common moulding sand is used for the core, and when swept up is as true as if turned in a lathe. When the flask is rammed up and the pattern removed both ends are open to the full size of the flange. When the core is set the chills close up the ends except the holes for bolt cores, and the projecting V ribs are pressed into the sand and make a perfect stop to prevent the iron from running out.

Cores of the size of the bolt holes and some three or four inches in length are made and passed through the chills until they strike the green sand, so that when the pipes are cast the bolt holes are more nearly correct than the ordinary drilled holes.

For making the bolt hole cores we have blocks like the cylinder of a revolver, Fig. 4, with several holes in which the cores are made and baked, turning them out as perfect as if made by machinery. The faces of the pipe are smooth and good enough to pack with rubber gaskets.

This all seems simple enough now, but it worked with indifferent success until we learned the trade, and in learning the trade the apprentices made by far the best headway.

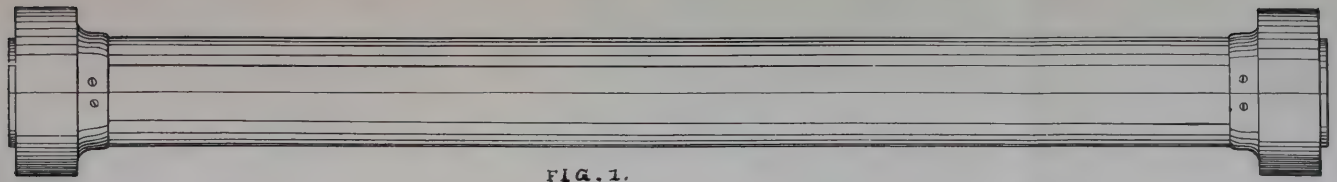


FIG. 1.

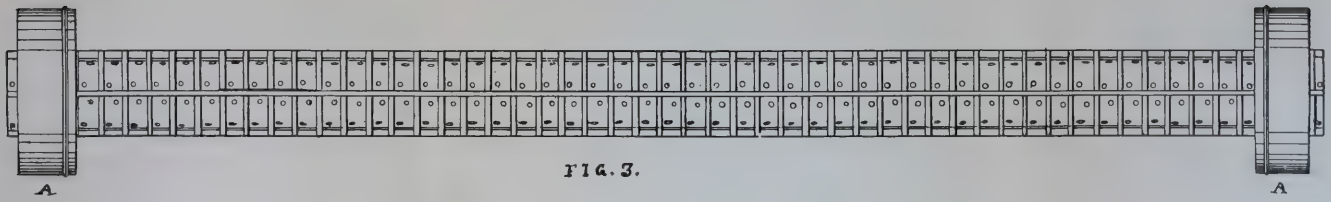
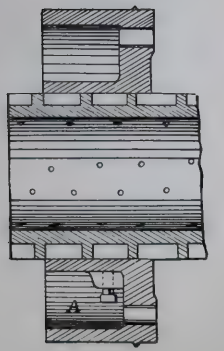
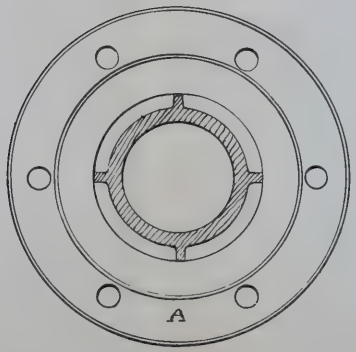


FIG. 3.





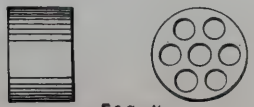


FIG. 4.

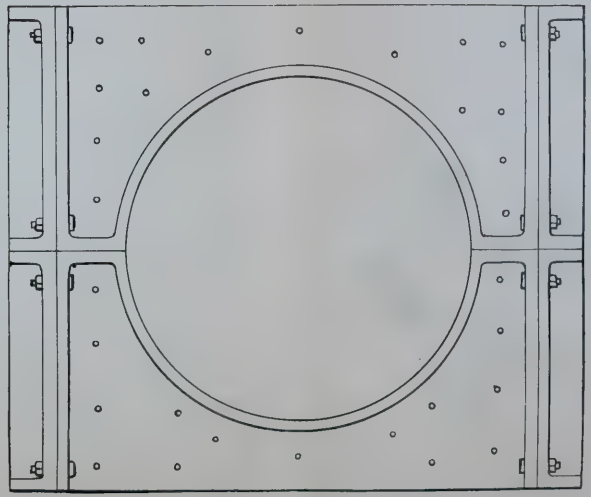


FIG. 2.

REMARKS UPON THE ORDINARY FORM OF BESSEMER INGOT CRANES.

BY

GRAM CURTIS, NEW YORK.

The crane most generally met with in our Bessemer works is shown in Fig. 1. It is top-supported and has a hollow cylindrical mast of cast-iron, made in three pieces. The top and bottom pieces are carefully turned, each with a tapered end which fits a turned socket in the corresponding end of the middle piece. The top piece passes through a block in the roof, which forms the top support to the crane. The bottom piece is made the plunger of the hydraulic cylinder at the base, and the middle piece carries the wrought-iron jib and tie rods.

It is the purpose of this paper to follow the principal strains developed by a load upon such a crane, call attention to some weak points of the mast, and to suggest another, and in some respects a better, form of mast and cylinder.

Referring to Fig. 1, and also to Fig. 2, which shows merely the axis $a\ b$ of the mast with the forces acting upon it:

a is point of lateral support to mast at cylinder.

b is point of lateral support to mast at block in roof.

c and d are the projections upon the axis of mast of the pins in tie rods.

The weight of the jib with its load tends to revolve the mast towards itself, and for a given load this tendency is obviously greatest when the load is at the outer end of the jib.

Avoiding as far as possible, in the body of this paper, the mathematical formula, which will be found in the appendix, let us assume that a certain weight, W,—which includes the weight of the jib and ties, etc.,—placed at the outer end of the jib, is the greatest load that can be safely borne by the crane. W then creates the force P at c, and the force P' at d, and these forces in turn develop the resistances p' at a and p at b, and we may therefore neglect the jib and tie and consider the mast as a beam held at rest by the forces p, P', P, and p', and these forces by tending to distort the mast tax its strength.

In order to get the full use of the mast it ought to be taxed up to its safe limit, but at no place beyond it. In Fig. 2 the lines x-x, x'-x', x''-x'' are the lines of the safe elastic limit of the mast, constructed from formulæ which may be found in the appendix. That is, the length of the perpendicular distance from any point in the axis of the mast, $a\,b$, to this line, gives the measure of the resistance to bending which the mast will offer at that point, when the extreme tensile strain upon that cross-section of the mast is 5,000 lbs. per square inch—the limit to which it is deemed safe to expose cast-iron. We notice at the points t and t' where respectively the top and the bottom pieces are abruptly reduced from 13 inches diameter to 12 inches diameter, that the elastic resistance (see x') is considerably reduced. It is here 750,248 inch-lbs., therefore the distorting tendency of the forces p, P', etc., or the bending moment, as it is called, must not be at these points greater than the above amount. Now the weakest position of this mast is when it is at its extreme upper point of stroke. t' is then 123 inches from the force p', and hence p' multiplied by 123 inches must equal 750,248 inch-lbs., from which it follows that p' must be 6,100 lbs. By means of p' and formulæ given in appendix, we find that W is 6,521 lbs., and deducting for the weight of jib, tie-rods, etc., their weight reduced to end of jib, 1,891 lbs., we have left 4,630 lbs. as the extreme load which may be safely handled by this nominally 10-ton ingot-crane, with a total lifting power of 39,810 lbs., under 300 lbs. hydraulic pressure. From this total lifting power, deducting

Weight of mast (calculated) . . .	8,950 lbs.
" " jib, etc. " . . .	3,268 "
Friction at a and b (33% × p) . . .	4,066 "
" in stuffing box (say) . .	4,000 "
Making a total of	20,284 lbs,

we have left 19,526 lbs. with which to lift 4,630 lbs.; that is, the extreme load that can be safely handled is not quite 24% of the capacity of the crane.

These reductions in the diameter of the mast are certainly very unnecessary, and at the same time very serious, errors in the design of the crane. Worse places for these reductions could not have been selected, and the error seems to have been copied into many,

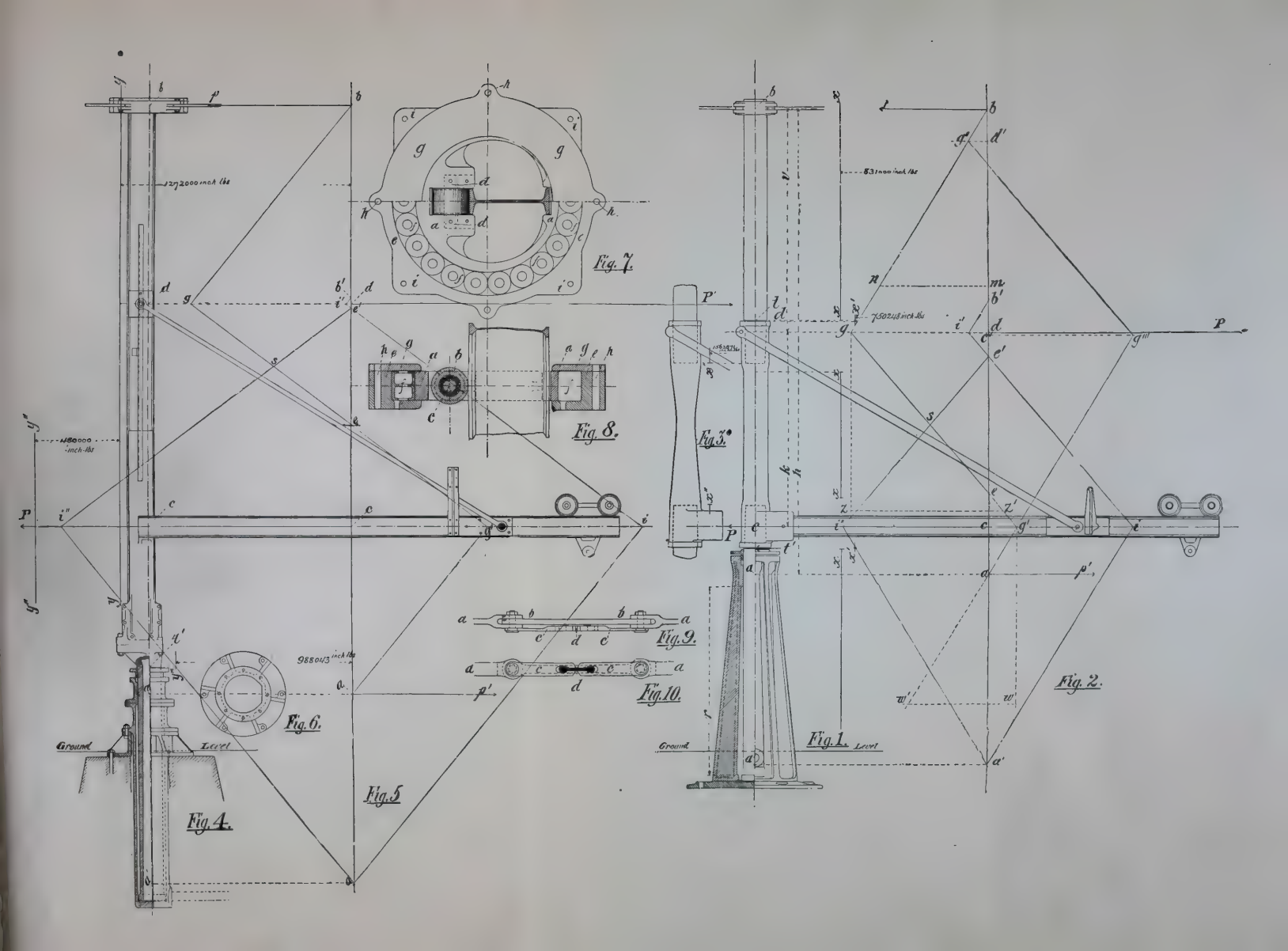


Fig. 1.

Fig. 2.

Fig. 3.

Fig. 4.

Fig. 5

Fig. 6.

Fig. 7.

Fig. 8.

Fig. 9.

Fig. 10.

if not most, of the ingot cranes in use. The breaking of these cranes at one of the places referred to (generally at the upper point *t*) is not an unusual occurrence, and in view of this danger, the maximum load, in at least one of our Bessemer Works, has been limited to 3 tons (which is however more than the safe limit), and in all the Bessemer Works large loads on these cranes are handled very cautiously. By forming the top and the bottom pieces as shown in Fig. 3, merely carrying the full diameter 13 inches, all the way, and, as soon as the length of stroke will permit, slightly enlarging the mast before it enters the socket, the net load which may be handled with safety will be increased to 6,697 lbs.,—a gain of over 44 per cent.

Having obtained the value of *p*, we can by means of formulæ, given elsewhere, construct the lines of bending moments. This construction is shown in Fig. 2. When the crane is down *g b* is the line of moments for the upper part of mast *d b*, *g g'* is the line of moments for the middle part *d c*, and *g'a* is the line for the lower part *a c*. It will be noticed that the line *g g'* intersects the axis *a b* at *e*, locating a section of the mast at which there is no bending strain.

When the crane is in its highest position, *b g''* becomes the line of moments for the upper part, *g''g'''* the line for the middle part, and *g''' a* the line for the bottom part. Transferring these lines to their proper position relative to Fig. 1, we see that the point of no flexure, or the neutral section of the mast, has traveled some distance up the mast during its stroke. We also find, as might have been expected, that the elastic strain sustained by any cross-section of the mast varies considerably during the stroke. Combining the two sets of moment lines we get *a'-i''-s-g-b*, the diagram for determining the form of a mast of uniform strength safely to sustain the load *W* at the outer end of the jib. It gives the maximum bending moment to which each cross-section of the mast is subjected by this load at some one time during a full stroke. This may now be compared with the lines of elastic resistance *x—x*, *x'*, etc., and it can at once be seen at what points the mast is strong and at what points weak. The small moment at *s*, with the moments increasing above and below it, calls for a middle piece of the shape given in Fig. 3, and shows how unnecessary is the strengthening of this part of the mast by heavy ribs, as is sometimes done, especially in ladle cranes.

Before speaking of the modified form of mast for a crane of the

type we have been considering, I wish to call attention to the conflicting character, or, to say the least, the independent character, of some of the elements which are to be combined in determining the size of its various parts.

1st. *The length of the jib.* This, with the load, creates the bending strain on the mast, and with the 2d element, *the stroke of the crane*, it determines the diameter of the ram, thus fixing the lifting area to be acted upon by the 3d element, namely, *the hydraulic pressure.* Any two of these being given, the 3d practically becomes prescribed within certain limits, in order that the crane shall not be overtaxed or broken down by its own lifting power. If, however, they are all fixed, *we may, or we may not*, be able to construct a crane that shall be safe under the greatest load it can lift.

In the case we are about to consider all of these elements have been fixed; the first and second by convenience, and the third, probably, arbitrarily.

We will take the same sized ram as used in previous crane, and the same length (123 inches) of the unsupported cylindrical part at full stroke. The annular cross-section of this ram (13 inches outside and 7″ inside diameter) gives, at 5,000 lbs. per square inch tensile strain, an elastic moment of 988,043 inch-lbs., which divided by 123 (the unsupported length) gives 8,033 lbs. for the safe limit for the forces p' and p acting at a and b. This is the limit of strength of the ram and must not be exceeded; but by separating a and b, which may easily be done by sinking the cylinder into the ground, we increase the power of this limit for sustaining a load at the outer end of the jib.

Sinking the cylinder has several advantages: it increases its stability without widening its base, permits of a lighter shell, and allows the use of a smaller base-plate and lighter foundations. There are, however, some objections to it: the principal ones are placing the stuffing-box where it is more exposed to dirt, etc., and bringing the projecting parts of the mast closer to the working level. We have chosen 4 ft. above ground for the top of gland; this avoids, in a measure, the above objections, and permits the safe handling of a load of 8,918 lbs. net. By using a solid ram we may increase this net load nearly 1,000 lbs., and by making it hollow, with diameters as given above—but using steel instead of cast-iron—the safe load would be about 18,000 lbs., which might be still further increased by sinking the cylinder lower.

Having found p' (= 8,033 lbs.) we may, with the stroke and height of mast—given elsewhere—construct the diagram of bending moments—Fig. 5—and from it proportion our mast. A cast-iron mast of this size, of adequate strength, will be found cumbersome; a better mast may be made of wrought iron—a heavy 15″ I beam as shown. The line yy is the line of elastic moments as found from table of I Beams of the Union Iron Mills. We see that opposite the jib the strength of the I beam is not great enough. It is at a place, however, where it may easily be strengthened, and probably the cheapest way of doing so is by well-fitted cast-iron fish-plates as shown. The line $y''y''$ is the increase of the elastic moment due to these plates, which clasp the lower end of the beam, and by very heavy flanges at the bottom receive the ram. Projections from these castings are carefully fitted into notches in the flanges of the beam. The ram immediately upon leaving the gland of the cylinder is enlarged to meet the casting just described. The cylinder is made with a flange—or with 8 separate ribbed lugs if desired—around its body, about 15 inches from its top end. The form of base-plate (see, also, Fig. 6) is light, and admits of through bolts for securing the cylinder.

The *top-support* for this form of mast is shown in Figures 7 and 8. It consists of a cast-iron ring a, which carries a wheel b, running on friction rollers. The steel shaft c is about $2\frac{1}{2}$″ diameter, and is flattened bottom and top for a few inches on each end, so as to set into sockets at d, d in ring a and be held without revolving. The frame e has a lower ledge or flange to support the ring a and the light cast-iron rollers f, f. The cover g secured by bolts through the holes hh is placed over the ring a and rollers f, f. The lugs i, i receive the guy-rods. With care in casting the different parts, this top-support can be fitted up with very little machine-work. The rollers f, f are free, as are also the rollers in the wheel b. The former being short in proportion to their diameter, have no tendency to fall on their sides.

The calculated weights of masts and cylinders of these cranes are as follows:

Crane—Figure 1.

Mast	8,950 lbs.	
Cylinder	7,220 "	
Base-Plate	3,981 "	
		20,151 lbs.

Crane—Figure 4.

Mast	Cast-iron.....	5,809 lbs.	
	Wrought iron.	1,970 "	
Cylinder.....		4,187 "	
Base-Plate.....		2,097 "	
			14,063 lbs.

Difference in favor of Crane, Fig. 4: 6,088 lbs.

The mast and cylinder of crane, Fig. 4, compare favorably with those of Fig. 1 as regards cost of construction; the top support, however, is more complex. Its lifting power, like the crane of Fig. 1, however, is far beyond its safe load, as is shown by the following:

13″ dia. = 132.7″ area × 300 lbs. pressure = ...		39,810 lbs.
Weight of mast	7,779 lbs.	
" jib, etc.....	3,268 "	
Friction, 33 per cent. of p.....	2,678 "	
" at b, assume.....	500 "	
" in stuffing box, assume	4,000 "	
		18,225 "
Leaving a net lifting load of.....		21,585 lbs.

with which to lift 8,918 lbs., or the safe load is little over 41 % of the power of the crane. It would seem that there is room here for the introduction of a "breaking block," or a piece the breaking of which without injury or derangement to the crane, would give warning that the load was exceeding the safe limit.

In Figs. 9 and 10 is shown an arrangement designed for this purpose: one is introduced into each tie rod. The tie rod $a\ a$ is forked, and there is inserted a link of tough, fibrous iron, having its cross-section of such a size that the bar will commence to stretch under the maximum load: $b\ b$ represents this bar, and $c\ c$ are castings carrying a small tell-tale bar d (shown in solid black) of brittle cast-iron, with a very small cross-section. Any stretch of b will cause the breaking of d, and this, together with the hanging down of the castings $c\ c$, reveals the fact that the safe limit of the crane has been reached. The tell-tale bar d goes into place from the back, when the link $b\ b$ is inserted, and a small lug or flange, which the bar carries, prevents it from working through. It therefore

remains loose until bound or broken by the stretch of the link, and as soon as this occurs the ends of the castings drop as described. Every time the crane is strained beyond its safe limit, new links *b b* and new bars *d* must be inserted.

Having noticed such serious defects in the ordinary form of ingot-crane, it may not be out of place, in conclusion, to mention a form of crane in which these defects may be avoided, namely, the Wellman, or rolling jib crane. This crane is admirably adapted for safety and strength, and also for economy of water. The two wrought-iron beams which form the mast may be proportioned to resist the bending strain from any desired maximum load, and the cylinder (placed between them) proportioned so that a greater load cannot be lifted. The improved form of these cranes has two concentric rams, and by using the inner or smaller ram for light loads an economy of water is effected.

For economy, however, the hydraulic crane is not conspicuous. As much work is expended in lifting an empty crane as is required to raise the same when loaded to its full lifting capacity: this follows from the fact that the same number of cubic inches from the accumulator are required in each case. With the empty crane, the surplus work is expended in friction in pipes, valves, etc.

Appendix.

Referring to Figures 1, 2, 4, and 5,

a = point of lateral support to mast at cylinder.

b = " " " " at block in roof.

c & d = projections on the axis of the mast of the pins in the tie rods.

h = distance from a to b = 263″ (in Figs. 1 & 2) = 331″ (in Figs. 4 & 5).

k = distance from c to d = 110″ (in Figs. 1 & 2) = 125″ (in Figs. 4 & 5).

v = variable dist. b to d = 126″ to 18″ (in Figs. 1 & 2) = 112″ to 4″ (in Figs. 4 & 5).

l = working length of jib = 246″ (in Figs. 1 & 2) = 246″ (in Figs. 4 & 5).

r = stroke of crane = 108″ (in Figs. 1 & 2) = 108″ (in Figs. 4 & 5).

W = greatest weight, including ties, jib, etc., etc., reduced, that can be safely borne by the crane at the outer end of the jib.

Formula for elastic resistance of annular cross-sections is

$$M = .0982 \times \frac{D^4 - d^4}{D} \times f.$$

In which D = outside diameter
d = inside "
f = limit of strain for material—in this case 5,000 lbs. tensile strain per square inch.

By substituting in this equation the values of D and d given in the following table, we obtain the moment by which the lines $x\ x$, x' etc., are laid off:

	D	d	Moment (M)
From b to t	13″	9″	831,000 inch-lbs.
At t	12″	7″	750,248 "
Middle piece	16″	11″	1,561,840 "
" "	13″	9″	831,000 "
At t'	12″	7″	750,248 "
Ram	13″	9″	831,000 "

From which we see that at t and t' are the weakest moments in the mast. W should then produce at one or at both of these sections a bending moment = 750,248 inch-pounds. W causes the moment Wl, which reaches the mast at c and d as the forces P' and P, forming the moment Pk, which in turn develops the resistances p' and p at a and b, giving rise to the moment ph. Hence:

$$Wl = Pk = ph \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

The force p must then cause at t, or the force p' must cause at t', the moment 750,248 inch-pounds. The distance $t\ b$ varies with the stroke of the crane from 120″ to 12″, and simultaneously the distance $t'a$ varies from 15″ to 123″, hence p multiplied by 123″ must equal 750,248 inch-pounds, or p = 6,100 lbs, and from equation (1) we find P = 14,585 lbs., and W = 6,521 lbs. Hence the safe load is 6,521 − 1,891 = 4,630 lbs.; 1,891 lbs. being the weight of jib, ties, etc., reduced to the end of the jib.

The forces p, P', P, and p' form bending moments and develop in the mast equal resisting or elastic moments M.

Let x be the distance of any cross section of the mast from the point b, and let this distance increase from $x = 0$, to $x = h$. For bending moments in the mast we then have:

For the part $b\ d$, or from $x = 0$ to $x = v$,

$$px = M \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

For the part $d\ c$, or $x = v$ to $x\ v + h$, $px - P\ (x - v) = M$,
or $pv + p\ (x - v) - P\ (x - v) = M$; or factoring
$$pv - (P - p)\ (x - v) = M \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

For the part $c\,a$, or $x = v + k$ to $x = h$, $px - P(x - v) + P[x - (v + k)] = M$, or $p(v + k) + p[x - (v + k)] - Pk - P[x - (v + k)] + P[x - (v + k)] = M$, reducing $pv + pk + px - pv - pk - Pk = M$, and factoring

$$pv - (P - p)k + p[x - (v + k)] M = \ldots \quad (4)$$

If we make 1″ in the drawing to equal 100 lbs., then in Fig. 2, the line bp, 61 inches long and perpendicular to ab, the axis of the mast, represents the force p; and similarly the horizontal lines P'' P, and p' represent those respective forces. To construct equations (2), (3), and (4) we assume 100″ for the unit measuring the distance from any force to any cross section, lay off $x = bm = 100''$, and make $mn = p = 61''$; the line bn, continued to g, its intersection with the direction of P' is then the graphical construction of $px = M$, equation (2), or the line of moments for the part of the mast bd. In a similar manner, pv, being represented by the line gd, making gz (parallel to ab) $= x - v = 100''$, and the perpendicular $zz' = (P - p) = 84.85''$ the line gz' extended to g is the moment line for part cd. And in like manner (the line cg' representing $pv - (P - p)k$) making $g'w = [x - (v + k)] = 100''$, and $ww' = p$, the distance $g'a$ on the line $g'w'$ will be the moment line for the part ca. When the crane is at its extreme upper point of stroke c becomes c' and d becomes d', and hence bg'' becomes the moment line for bd', $g''g'''$ for $c'd'$ and $g'''a$ for $c'a$. Transferring this last set of moment lines to $a'i$ $i'b'$, its position relative to Fig. 1, and combining, we get a' i'' s g b, the diagram for mast of uniform strength. Diagram Fig. 5 is constructed in like manner, the same letters referring to like parts.

At t', Fig. 4, is the cross section limiting the strength of the ram to resist flexure; here $D = 13''$, and $d = 7''$, whence the limit of elastic movement M, is 988,043 inch-pounds. The distance $t'a = 123''$, and therefore putting $123'' + p = 988{,}043$ inch-pounds, we find $p = 8{,}033$ lbs., and by equation (1), $P = 21{,}271$ lbs., and $W = 10{,}809$ lbs.

The elastic moment of a heavy 15″ I-beam, deduced from the Union Iron Mills tables (safe uniform load for 1 foot span = 424′ tons) is

$$\frac{424 \times 2.000 \times 12}{8} = 1{,}272{,}000 \text{ inch-pounds.}$$

Assuming each splice plate to have a cross section at least 12′

high by 2″ broad, we have by substituting in the formula for elastic resistance of rectangular cross-sections, viz.:

$M = \frac{1}{6} bh^2 \times f$, 480,000 inch-pounds elastic resistance due to the plates.

For a solid ram, $d = 0$, we have $M = .0982 \times D^3 \times f = 1{,}078{,}727$ inch-pounds, whence $p = 8{,}770$ lbs., and $W = 11{,}800$ lbs., and net load $11{,}800 - 1{,}891 = 9{,}909$ lbs.

THE EVAPORATIVE POWER OF BITUMINOUS COALS.

BY

WILLIAM KENT, M. E., NEW YORK.

THE report made to the Navy Department in 1844 by Prof. Walter R. Johnson, of "Experiments on the Evaporative Power and Other Properties of American Coals," has long been accepted as a standard work of reference, not so much on account of the real value of the information it contains, as on account of the fact that, during the nearly forty years that have elapsed since its publication, no work on the subject of which it treats has appeared to supplant it. In many respects it is an admirable report, giving a faithful record of carefully conducted experiments, and including the proximate chemical analysis as well as the apparent evaporative power of the coals tested. It has, however, two very serious defects—it does not treat at all of any American coals mined west of Pittsburgh, and it does not give the real evaporative powers of such of the bituminous coals as were tested, but only their apparent evaporative powers as shown under conditions unfavorable to the development of the best results.

A pamphlet has recently been published by the Quartermaster-General of the U. S. Army, Gen. M. C. Meigs, entitled "Report on Fuel for the Army," which contains the results of 106 experiments with various coals, 75 with a vertical water-tube boiler known as the Little Giant, rated at five-horse-power, and 31 with a vertical water-tube boiler of about the same capacity, designed by Gen. Meigs. Of the experiments with the Little Giant boiler, 25 were made with Pennsylvania anthracites and 50 with semi-bituminous, bituminous, lignite, and cannel coals; with the other boiler six experiments were made with Pennsylvania anthracites, and 25 with semi-bituminous, bituminous, lignite, and cannel coals. A very much larger number of coals were tested than in Johnson's experiments, and the series included coals from nearly every section of the United States and also some foreign coals. In the letter transmitting the report to the Secretary of War, Gen. Meigs states that the object of the experiments was a careful determination of the *actual value, as fuel*, of the various kinds of fuel purchased and issued for the use of the army.

These numerous experiments having been conducted at Government expense, with all the facilities which the War Department is capable of affording, by Mr. L. M. Zuncker, "a mechanical engineer, educated at the Polytechnic School, Carlsruhe, Germany," in the light of the American experiments of forty years ago, and of various experiments in foreign countries in more recent times, it might be expected that this report would be an exceedingly valuable one, and that we would find in it either the actual value, as fuel, of the various coals of the United States, or, at least, their relative values as fuel for producing steam. As a matter of fact, however, the report is a disappointing one, and not at all valuable nor creditable to the department which issued it. It contains no analysis of the coals, nor any measure of their heating power. The various coals are used by the army as fuel probably more for heating purposes than for raising steam, yet the report assumes that the heating power of a coal is the same, relatively, as its power of raising steam "in a good steam boiler." If the report did contain even accurate determinations of the steaming power of the various coals without any attempt at determining their heating power when burned in a heating furnace, or stove, or grate, it would still be valuable, and would take the place of Johnson's report; but, instead, it has all the errors of Johnson in determining the relative steaming values of the bituminous coals intensified. All that the report does contain is simply a statement of what evaporative results were obtained from small quantities (145 to 1,200 lbs.) of various coals burned at approximately uniform rates of combustion, in a pair of boilers which were entirely unsuitable to the development of even the correct relative steaming power of nearly all of the bituminous coals, especially those mined west of the Alleghany mountains, and containing 30 per cent. or more of volatile matter.

Gen. Meigs himself recognizes that the results he obtained are inferior to Johnson's. "In order," he says, "to bring its [the Little Giant boiler's] inferior results to the same scale as Johnson's, which are assumed as exact, it has been necessary to use a co-efficient by which the results of the trials by the Little Giant boiler are corrected, in order to make them comparable with Johnson's." He says further: "The boiler used in Johnson's experiments on the evaporative power of coal was expressly constructed for that purpose. It was more economical, more efficient. The co-efficient to make the Quartermaster-General's office results comparable with Johnson's is 0.843, and dividing the Quartermaster-

General's office results by this fraction we have figures comparable with Johnson's."

The report does not state how this co-efficient was arrived at. It may have been obtained by averaging results, and is approximately correct for anthracite coals, and for the free-burning, semi-bituminous coals of Maryland; but for Pittsburgh coals, the results obtained with the Little Giant boiler, even after dividing by the co-efficient, are more than 10 per cent lower than Johnson's, with Newcastle (English) coal 30 per cent lower, and with Scotch coal, which happens to be the lowest in Johnson's whole list, over 11 per cent lower.

The results obtained by Gen. Meigs may be thus briefly summarized: With the Little Giant boiler, with 25 anthracite coals, the number of pounds of water evaporated from and at 212° per pound of coal varied from 8.68 down to 7.59 pounds, and after being divided by the co-efficient 0.843 from 10.29 down to 9.00 pounds. With the same boiler, with 49 bituminous coals, after being divided by the co-efficient, only two—a Somerset County, Pa., and a Cumberland, Maryland, coal—showed an evaporation of over 9 pounds, viz., 10 and 9.96 pounds. The third, a Colorado; fourth, a West Virginia; and fifth, a Colorado, showed respectively 8.59, 8.34, and 8.04 pounds. The sixth, a Pittsburgh coal, shows 7.84. The next five coals—two Pittsburgh, one Indiana, one New South Wales, one Indian Territory, and one Vancouver's Island—show over 7 pounds. Then come eighteen coals, including one from Pittsburgh, two from near Youngstown, Ohio, two Scotch, and one English coal, between 6 and 7 pounds; ten coals between 5 and 6 pounds, eight between 4 and 5 pounds, and one, a Utah coal, only 3.79 pounds. Thus 47 out of 49 bituminous coals, taken from nearly all parts of the world, give poorer results than the poorest obtained from the Pennsylvania anthracites.

With the boiler designed by Gen. Meigs, there were only 6 anthracites and 25 bituminous coals tested. It happens that two of the semi-bituminous coals, both from Somerset county, Penn., give better results, viz., 9.85 and 9.75, than any of the anthracites; then follow four out of the six anthracites, from 9.37 to 9.07; then one of the Pittsburgh coals appears, 9.07; then the other two anthracites, 9.04 and 8.87; and then the second Pittsburgh coal, 8.78. The two Pittsburgh coals which gave in these tests 8.78 and 9.07, showed in the Little Giant boiler test, even after dividing the results by the co-efficient, only 6.74 and 7.84 respectively the differ-

ences being respectively more than 23 and more than 13 per cent. This fact alone is sufficient to show the total unreliability of these tests. A Scotch, and an English coal also, which in the Little Giant boiler, after dividing by the co-efficient, gave only 6.25 and 6.07 pounds, in Gen. Meigs' boiler gave 7.61 and 7.52 pounds. The lowest coal on the list is a Dakota lignite, which gave 4.03 pounds evaporation; it gave 4.47 in the Little Giant test, after dividing by the co-efficient, and is the only coal in which an important difference in its favor appears in the latter test. Of the 25 bituminous coals tested in Gen. Meigs' boiler, 22 show results below the lowest of the six anthracites.

With both boilers, the tendency of the figures is to place the bituminous coals in general far beneath the anthracites in evaporative power. In this I think the tests are utterly misleading, and worse than worthless.

I have prepared a table (Table I. in the Appendix), which gives a selection of figures from various experiments on bituminous coals, including those of Gen. Meigs, arranged as nearly as possible in geographical order. The table also contains the percentage of refuse obtained in the trial, and the percentage of volatile matter, as determined by analysis, whenever these are given by the authorities consulted. Table II. gives the analyses of the coals whose analyses are reported.

The first portion of the table, headed "Continent of Europe," gives some of the results of the tests of Scheerer-Kestner and C. Meunier-Dollfus, reported to the Société Industrielle de Mulhouse. The first six coals whose percentage of volatile matter are given are nearly similar in composition to the Pittsburgh coals, except that they have a much greater percentage of ash. As these same coals were not tested by any other of the authorities here noticed, the results are scarcely comparable with those of American coals; but one point is worthy of notice: The Ronchamp coal, although containing a very high percentage of ash, gives the highest evaporation, and it contains much less volatile matter than the other five coals, while the Louisenthal coal, containing less ash than the Ronchamp, but the highest percentage of volatile matter, gives the lowest evaporation. This corresponds with the results both of Gen. Meigs and Prof. Johnson, in showing that the higher the percentage of volatile matter, the lower is the evaporative power (as shown by their boilers—not as might be shown under better conditions).

In the English coals, which are all highly bituminous, we notice that the two results of Johnson agree very fairly with the average results of Delabeche and Playfair; that in Johnson's results the highest evaporation corresponds with the lowest percentage of volatile matter; that in Delabeche's and Playfair's results the highest evaporation corresponds with the lowest percentage of *oxygen* and nitrogen, and *vice versa*, notwithstanding the fact that the lowest evaporation corresponds with the *lowest* amount of ash. We also observe that the results with Gen. Meigs' boiler are lower than either Johnson's or Delabeche and Playfair's, and that the results of the Little Giant boiler are the lowest of all.

In the Welsh coals, in Delabeche and Playfair's results, we notice that while the percentage of ash is higher than in the Newcastle coals, the evaporation is higher, and here also we trace the effect of lower oxygen, nitrogen and hydrogen, in increasing evaporative power (in their experiments). The tests by the Babcock and Wilcox boilers, both in London and in San Francisco, give results very much higher than Delabeche and Playfair's, the probable cause of which will be noticed hereafter.

In the Scotch coals, we are fortunate in having both Johnson's and Delabeche and Playfair's analyses, and the results of tests by five different authorities. Delabeche and Playfair's analyses show them to be very nearly the same as the Lancashire coals, and their evaporative tests of the two coals show nearly the same results. They show also that although the Scotch coal has a little less ash than the Welsh, its evaporative power is very much less, and this we connect with its higher percentage of oxygen, nitrogen and hydrogen.

The English and the Scotch coals appear very nearly alike in both Gen. Meigs' and the Little Giant boiler tests; but in both, and especially in the latter, both coals give very much poorer results than in any other boiler. For some unexplained reason, the Scotch coal figures the lowest in the whole list of Johnson, and more than twenty per cent. lower than Newcastle coal.

Since we have Delabeche and Playfair's analyses of Scotch and Welsh coals to compare with their evaporative tests, we may ascertain whether the difference in analysis is sufficient to account for the difference in evaporative results. From the formula, Heating Power $= 14500 \left\{ C + 4.28 \left(H - \frac{O}{8} \right) \right\}$ we obtain the theoretical heating power of the Welsh coal, 14,816 heat units, equivalent to

an evaporation of 15.35 lbs. of water from and at 212, and for the Scotch coal 14,136 heat units, equivalent to an evaporation of 14.65 lbs. As the actual results obtained were respectively 9.05 and 7.70 lbs., they show that Delabeche and Playfair obtained in actual test 59 per cent. of the theoretical heating power of the Welsh coal, and only 52.5 per cent. of the heating power of the Scotch coal—an economic result in favor of the Welsh coal of 12.4 per cent. $\left(\frac{59 - 52.5}{52.5}\right)$ Johnson obtained 47.4 per cent. of the theoretical heating power of the Scotch coal, the Meigs boiler 51.9 per cent., the Little Giant boiler (results divided by 0.843) 42.2 per cent., and the Babcock and Wilcox boiler 78.6 per cent., provided of course that the particular coals used in each of these tests had the same theoretical heating power.

But little can be said of the Nova Scotia coals, as we have only Johnson's two tests for comparison. The Pictou and Sidney coals seem an exception to the rule, already noticed, that the higher evaporative power corresponds under usual conditions with lower percentage of volatile matter as well as lower percentage of ash.

Coming to the Pennsylvania coals, we notice a group tested by Johnson, Nos. 30 to 35 inclusive, which are properly classed as semi-bituminous, having from 13.82 to 20.52 per cent. of volatile matter. They are especially noticeable from the fact that notwithstanding their rather high percentages of ash, they show the highest evaporative powers on Johnson's whole list. The two coals of Somerset County, Nos. 37 and 38, tested by Gen. Meigs, are coals of similar character, and they give the highest results of any bituminous coals tested by him, and, in the tests with the Meigs boiler, higher results even than any of the six anthracites. The high steaming quality of these coals is confirmed by the Babcock and Wilcox test of Cambria coal No. 44, containing only 13.24 per cent. of volatile matter. Notwithstanding the very high percentage, 25.1, of ash, the test showed an evaporation of 9.59 pounds of water per pound of coal, and 12.80 per pound of combustible, which latter figure exceeds the figures obtained in the tests of Scotch and of Welsh coal.

For a fair comparison with these coals we may turn to the Maryland coals, where Isherwood's, Johnson's and Little Giant tests all give high figures, and which are remarkably close ones, 9.69, 9.99, and 9.96. The Cumberland coal ranks second highest of the 50 bituminous coals tested in the Little Giant boiler, and also the

highest in Johnson's tests. It would appear that these coals, containing from 13 to 20 per cent. of volatile matter, notwithstanding occasionally high percentages of ash, prove good steaming coals under a variety of conditions and in a variety of boilers. They seem especially adapted to marine, vertical tubular and other internally fired boilers, which have heating surfaces all around the fire, and no special appliances for promoting perfect combustion.

With No. 36, in the Pennsylvania coals, we strike a very different quality of coals from the above. The Pittsburgh, or Monongahela River coals, are the type of this class. They generally have small percentages of ash, and high percentages of volatile matter (30 to 40 per cent.), approaching in composition the English, Scotch and Welsh coals, although not often found as pure as these latter. With these coals we reach the real difficulties of burning bituminous coals, and in consequence the results obtained under varying conditions, and with various boilers, differ widely. We notice that Pittsburgh coal No. 40 gave an evaporation of only 6.74 pounds in the Little Giant boiler, and 8.78 in the boiler of Gen. Meigs. Johnson found 8.20 for a Pittsburgh coal, while the Babcock and Wilcox tests gave from 8.12 for fine slack to 10.47 for lump (No. 46.)

Still more discordant results than these have been obtained from the same identical lot of Pittsburgh coal when burned under different boilers in different furnaces. At the Cincinnati Exposition of 1879, Mr. John W. Hill made five tests, in as many different furnaces, of Pittsburgh coal No. 2, all of the furnaces having been designed for "smoke consumers." The evaporation per pound of coal from temperature of feed varied from 5.839 to 9.688 pounds, but according to Mr. Hill's corrections for "heat in the steam," it varied from 4.828 to 12.450 pounds.

The Virginia coals tested by Johnson contain on an average less volatile matter than the Pittsburgh coals, and follow the general rule of showing a correspondingly higher evaporation.

The bituminous coals west of Pittsburgh were not tested by Johnson, and the tests by Gen. Meigs do not show the analyses, so that we have scarcely enough data for comparison. We notice, however, the very low figures, 6.82 pounds and under, for the coals of Tennessee, Ohio and Nebraska, all of which contain less than 7 per cent of refuse. The high results obtained by the Babcock and Wilcox boilers from Illinois "run of mine" coal (name of mine not known) and Indiana block coal, 9.49 and 9.47 respectively, are no-

ticeable, but as we have not the analyses no accurate conclusion can be drawn from them.

We come now to a very peculiar coal from Staunton, Ill., tested under a Babcock and Wilcox boiler at Springfield, O., which gives the figure 5.09—remarkably low as compared with all the other Babcock and Wilcox tests. As shown in Table III., the test was made with the same boiler that was used in testing the Jackson, O., nut coal, which gave an evaporation of 8.93. Not only were the economic results obtained from this Staunton coal very low, but the capacity of the boiler was largely reduced while using it, so that while 460 horse power had been developed, with 48 square feet of grate surface, with the Ohio coal, only 246 horse-power was obtained with 60 square feet of grate surface, with the Staunton coal. To explain this anomalous result we must turn to the analysis. It shows only 26.30 per cent. of fixed carbon, and 57.11 per cent of volatile matter, and is thus totally unlike all the other coals whose analyses are given in connection with boiler tests, the nearest approach to it being the Liverpool coal in Johnson's test, which had more than twice as much fixed carbon, and only 39.96 per cent. volatile matter. There is one coal in the list of analyses, Table II., of which, however, there is no boiler test reported, which is the only coal analysis I have found showing a higher percentage of volatile matter than the Staunton coal, and that is the Boghead coal of Linlithgowshire, Scotland, which, according to Dr. Penny, contains 67.95 per cent. of volatile matter, and only 9.54 per cent. of fixed carbon. I regret not to be able to give a complete ultimate analysis of the Staunton coal, from which to determine its theoretical heating value, but if it shows a relatively high percentage of hydrogen, and a small percentage of oxygen, nitrogen and moisture, as does the Boghead coal, then its theoretical heating power must be high, and the only reason it did not give good results in the boiler test must be that it was not properly burned. A broad distinction must be drawn here between the boiler used to absorb the heat developed from burning coal, and the furnace under the boiler in which the coal was burned. There can be no question in this case as to whether the boiler had sufficient absorbing surface, for if it could develop 460 horse power with an evaporation of 4.11 pounds water per square foot of heating surface per hour, and 8.93 pounds of water per pound of coal, it should be able with even greater economy to develop only 246 horse power, at a rate of evaporation of only 2.27 pounds of water per square foot of heating surface per

hour. If the coal had been burned in the furnace the boiler would have absorbed the heat. The conclusion is that the furnace under the boiler, or possibly the method of firing, which was well adapted to Jackson, O., coal, was not well adapted to Staunton, Ill., coal, and further experiments with various kinds of furnaces should be made to determine what furnace is best adapted to it.

This paper has already grown to sufficient length, without entering upon the subject of the character of furnace best adapted to burn the different qualities of bituminous coals. In fact there are not enough data existing for a proper treatment of this very important subject. I may briefly state that my present opinion is that almost any kind of a furnace will be found well adapted to burning anthracite coals and semi-bituminous coals containing less than 20 per cent. of volatile matter; that probably the best furnace for burning those coals which contain between 20 and 40 per cent. volatile matter, including the Scotch, English, Welsh, Nova Scotia, and the Pittsburgh and Monongahela River coals, is a plain grate-bar furnace with a fire-brick arch thrown over it, for the purpose of keeping the combustion chamber thoroughly hot; that the best furnace for coals containing over 40 per cent. volatile matter will be a furnace surrounded by fire brick with a large combustion chamber, and some special appliance for introducing *very hot* air to the gases distilled from the coal, or preferably, a separate gas producer and combustion chamber with facilities for heating both air and gas before they unite in the combustion chamber. The character of furnace to be especially avoided in burning all bituminous coals containing over 20 per cent. of volatile matter, is the ordinary furnace in which the boiler is set directly above the grate bars, or in which the heating surfaces of the boiler are directly exposed to radiation from the coal on the grate. The question of admitting air above the grate, which was favorably settled by Chas. Wye Williams forty years ago, is again unsettled. The London *Engineer* recently said: "All our experience, extending over many years, goes to show that when the production of smoke is prevented by special devices for admitting air, either there is an increase in the consumption of fuel or a diminution in the production of steam. * * * The best smoke preventer yet devised is a good fireman."

The English and French experiments on the evaporative power of bituminous coals are of little value for this country, since the coals described in these experiments were of limited variation in composition. Johnson's experiments are of little value, since they

included no bituminous coals west of Pittsburgh. Gen. Meigs' experiments are worthless, since neither of his boilers was adapted to the thorough combustion of highly bituminous coal. The Babcock and Wilcox boiler tests are valuable in showing that with proper furnace settings, very much higher results can be obtained from the highly bituminous coals than would have been believed from the experiments of Johnson and Meigs. Their great demerit is that they are not yet sufficiently extensive. Table III. gives the details of the Babcock and Wilcox tests, as far as I have been able to obtain them; this complete list has not hitherto been published. All of these tests were made with the furnace supplied with a fire-brick arch for preventing the radiation of heat from the grates directly to the boiler, and for keeping the combustion chamber hot. They were made with boilers of the same kind, and practically the same proportions, but in different parts of the world, by different experimenters, and at different rates of evaporation, caused chiefly by the different steam requirements of the establishments in which they were situated.

At the bottom of Table I., I have placed the best recorded results obtained from anthracite coal by Johnson's, Meigs', the Little Giant, and Babcock and Wilcox boilers, as a standard for comparison with the bituminous coals. The following table shows the relative value of the several bituminous coals therein named, as tested by each of the boilers, the best results being selected out of those given in Table I. and the figures for anthracite being taken at 100 per cent:

Relative Steaming Values of Bituminous Coals. Anthracite=100.

Coals.	Johnson's Boiler.	Gen. Meigs' Boiler.	Little Giant Boiler.	Babcock and Wilcox Boilers.
Newcastle, Eng.....	84.5	81.1	59.0	——
Welsh.....	——	——	——	109.6
Scotch.....	67.8	81.2	60.7	109.5
Cambria Co., Pa., semi-bit.	90.1	——	——	91.2
Somerset Co., " " "	——	105.1	97.2	——
Cumberland, Md., " "	97.5	——	96.8	——
Pittsburgh, Pa.....	80.0	96.8	76.2	99.5
Ohio.....	——	——	64.8	84.9
Vancouver Island.....	——	81.0	68.5	85.7

From the above table it will be seen that by all of the tests of the semi-bituminous coals, their value as compared with anthracite varies only from 90.1 to 105.1 per cent., confirming what has

already been said, that these coals give excellent results under a great variety of conditions. The value of the Scotch coals appears to vary between 60.7 and 109.5 per cent. of the value of anthracite, the same identical coal giving 60.7 per cent. in the Little Giant boiler, and 81.2 per cent. or more than one-third better in Gen. Meigs' boiler. The value of Pittsburgh coal is from 76.2 to 99.5 per cent. of the value of anthracite, the experiments of Gen. Meigs with one coal giving the figures 76.2 and 96.8 per cent. The relative value of bituminous coal is therefore a variable quantity, dependent upon the conditions under which it is burned.

I hope the facts here imperfectly outlined may draw attention to the possibility of obtaining better results from the highly bituminous coals of our Western States than are generally obtained in practice, or than those shown in the experiments here recorded. The whole subject of the proper methods of burning bituminous coals of various compositions needs to be re-opened. It must be studied from the bottom, beginning with both proximate and ultimate analyses of the coals, and including scientific determinations of total heating power as well as practical tests under steam boilers. The subject is of immense importance to the industries of the West and South. It would be well if the government would undertake the series of accurate experiments necessary to lead to a solution of the problems involved, but if such experiments are to be conducted as imperfectly, and the results obtained so misleading, as those reported by Gen. Meigs, they had better be left to private enterprise.

Table I.—Evaporative Power of Bituminous Coals.

Number for Reference.	Name of Coal and Location of Mine.	Percentage of Refuse by Boiler Test.	Percentage of Volatile Matter by Analysis.	Pounds of Water Evaporated Per Pound of Coal, from and at 212°.				
				Scheerer - Kestner and Meunier-Dollfus Elephant Boiler.	Prof. W. R. Johnson. Two-Flue Boiler.	Gen. M. C. Meigs. Meigs Boiler.	Gen. M. C. Meigs. Little Giant Boiler. Results divided by 0.813.	Babcock and Wilcox Boilers.
	Continent of Europe.							
1	Ronchamp.....	17.5	23.19	8.58	....	....	....	....
2	Friedrichsthal.....	18.4	33.79	7.55	....	....	....	....
3	Duttweiler.....	17.7	32.19	8.07	....	....	....	....
4	Louisenthal.....	16.9	38.42	7.18	....	....	....	....
5	Altenwald.....	16.1	31.86	8.18	....	....	....	....
6	Heinitz.....	12.6	33.98	8.14	....	....	....	....
7	Sulzbach.....	14.9	....	7.79	....	....	....	....
8	Von der Heydt.....	16.3	....	7.61	....	....	....	....
9	Blanzy, Montceau.....	16.7	....	7.48	....	....	....	....
10	" Anthracite.....	22.9	....	7.91	....	....	....	....
11	Creusot.....	10.7	....	9.67	....	....	....	....
	England.			Delabeche and Playfair				
12	Newcastle. Av. of 18.....	....	....	8.01	....	....	....	....
13	Derbyshire and Yorkshire. Av. of 7.....	....	....	7.58	....	....	....	....
14	Lancashire. Av. of 28....	....	....	7.94	....	....	....	....
15	Liverpool.....	5.3	39.96	....	7.84	....	....	....
16	Newcastle.....	6.3	35.83	....	8.66	....	....	....
17	Davison, West Hartley....	6.0	....	....	....	7.60	....	....
18	Cowper. Newcastle-on-Tyne.....	6.1	....	....	....	7.52	6.07	....
19	Cowpen Cambois. W. Hartley...	6.2	....	....	....	7.04	....	....
	Wales.							
20	Welsh. Test in London...	7.5	....	....	....	....	....	11.53
21	Cardiff Lump. Test in San Francisco. Av. of 2....	10.9	....	....	....	....	....	9.85
22	Welsh. Av. of 37.....	....	....	9.05	....	....	....	....
	Scotland.							
23	Scotch. Av. of 8.....	....	....	7.70	....	....	....	....
24	Scotch.....	10.8	39.19	....	6.95	....	....	....
25	Scotch Splint.....	6.7	....	....	....	7.61	6.25	....
26	Ardrossan, Fergushill.....	5.0	....	....	....	....	6.10	....
27	Scotch. Test at Greenock.	7.0	....	....	....	....	....	11.52
	Nova Scotia.							
28	Pictou. Av. of 2.....	12.8	26 90	....	8.63	....	....	....
29	Sidney.....	6.4	23.81	....	8.11	....	....	....

Table I.—Continued.

Number for Reference.	Name of Coal and Location of Mine.	Percentage of Refuse by Boiler Test.	Percentage of Volatile Matter by Analysis.	Pounds of Water Evaporated Per Pound of Coal, from and at 212°.				
				Scheerer-Kestner and Meunier-Dollfus. Elephant boiler.	Prof. W. R. Johnson. Two-Flue Boiler.	Gen. M. C. Meigs. Meigs Boiler.	Gen. M. C. Meigs' Little Giant Boiler. Results divided by 0.843.	Babcock and Wilcox Boilers.
	Pennsylvania.							
30	Dauphin, Susquehanna....	16.5	13.82	....	9.34	...	....	....
31	Lycoming Creek.....	13.1	13.84	....	8.91	....	....	....
32	Blossburg.....	11.5	14.78	....	9.72	....	....	....
33	Quin's Run.....	9.3	17.97	....	10.27	....	....	....
34	Karthaus	8.0	19.53	....	9.09	....	....	....
35	Cambria Co	9.5	20.52	....	9.24	....	....	....
36	Pittsburgh.....	9.5	36.76	....	8.20	....	....	....
37	Standard C. Co., Brothers Valley, Somerset Co.....	11.0	....	....	....	9.85	10.00	....
38	Philson Iron Coal Co., Berlin, Somerset Co.....	9.1	....	....	....	9.75	....	....
39	Simpson Horner & Sons, near Pittsburgh.....	7.9	....	....	....	9.07	7.84	....
40	Thos. Fawcett & Sons, near Pittsburgh.....	6.0	....	...	....	8.78	6.74	....
41	Geo. Lysle & Sons, near Pittsburgh.....	5.5	....	....	....	....	7.62	....
42	Hornet Coal Co., near Pittsburgh.....	5.4	....	....	....	....	7.22	....
43	Powelton, 11,400 lb. mixed with 2,790 Anth. Scr'gs..	8.8	....	....	....	....	....	11.32
44	Johnstown, Cambria Co., Fine Slack.....	25.1	13.24	....	....	....	....	9.59
45	Pittsburgh, fine slack.....	12.3	....	....	....	...	....	8.12
46	" 3d Pool, lump.	4.8	....	....	....	....	....	10.47
47	Castle Shannon, near Pittsburgh, nut.....	13.0	....	....	....	....	....	8.96
48	Castle Shannon, near Pittsburgh, lump.....	9.0	31.69	....	....	...	....	10.13
49	Castle Shannon, near Pittsburgh, $\frac{3}{8}$ nut, $\frac{5}{8}$ lump....	10.5	....	....	....	....	....	10.00
	Maryland.							
50	Cumberl'd, Blan. Avon Mine	8.3	....	....	....	....	9 96	....
51	Av. of 5 Md. Free-burning bit.....	11.03	14.21	.... Isherwood.	9.99	...	....	....
52	Cumberland.....	8.25	...	9.69	....	....	....	....
	Virginia.							
53	Average of 10 Coking Coals, near Richmond.....	11.47	30.36	....	8.59	....	....	....
	West Virginia.							
54	W. Va. Splint, Paint Creek, W. Va.....	8.1	....	....	....	8.34	8.34	....

Table I.—Continued.

Number for Reference.	Name of Coal and Location of Mine.	Percentage of Refuse by Boiler Test.	Percentage of Volatile Matter by Analysis.	Pounds of Water Evaporated Per Pound of Coal, from and at 212°.				
				Schoerer-Kessler and Mennier-Dolfus. Elephant Boiler.	Prof. W. R. Johnson. Two-Flue Boiler.	Gen. M. C. Meigs. Meigs Boiler.	Gen. M. C. Meigs' Little Giant Boiler. Results divided by 0.85.	Babcock and Wilcox Boilers.
	Tennessee.							
55	Battle Creek, South Pittsburgh	6.6	....	....	....	....	6.76	....
56	Coal Creek, near Knoxville	5.6	....	....	....	....	6.75	....
	Ohio.							
57	Kyle Coal Co., S. E. of Youngstown	4.8	....	....	....	...	6.82	....
58	Vienna C. & I. Co.	6.1	...	....	....	....	6.71	....
59	Hubbard Mine	5.1	....	....	....	....	5.98	....
60	Jackson Co., nut	9.6	....	....	....	....	....	8.93
	Indiana.							
61	Ind'a Cannel, Daviess Co.	24.8	....	....	....	7.32	7.12	....
62	Indiana Block	....	....	....	....	....	....	9.47
	Illinois.							
63	Illinois "Run of Mine"	....	....	....	....	....	....	9.49
64	Staunton, fine nut	17.7	57.11	....	....	. ..	....	5.09
	Missouri.							
65	Lexington Coal Shaft	12.2	....	....	....	....	6.51	....
	Nebraska.							
66	Rocky Mountain. Rocky Spring Mine	6.5	....	....	....	6.01	4.93	....
	Kansas.							
67	Leavenworth Coal Shaft	11.1	....	....	....	6.49	6.42	....
	Indian Territory.							
68	Macallester, Tobosky Co.	5.8	....	....	....	7.68	6.96	....
	Texas.							
69	San Antonio Mining Co., near S. A.	11.5	....	....	....	....	4.46	....
	Colorado.							
70	Mitchell & Co., La Plata, near Ft. Lewis	10.9	....	....	...	7.49	....	....
71	Canon Coal, Fremont Co.	10.	....	....	...	6.45	6.01	....
72	Trinidad, Starksville	14.8	....	....	....	....	8.59	....
73	El Moro, near Trinidad	15.8	....	....	....	....	8.04	....
	New Mexico.							
74	Los Cerillos bit., Ortez Grant	13.3	....	....	....	8.60	...	....

Table I.—Continued.

Number for Reference.	Name of Coal and Location of Mine.	Percentage of Refuse by Boiler Test.	Percentage of Volatile Matter by Analysis.	Pounds of Water Evaporated Per Pound of Coal, from and at 212°.				
				Scheerer-Kestner and Meunier-Dollfus. Elephant Boiler.	Prof. W. R. Johnson. Two-Flue Boiler.	Gen. M. C. Meigs. Meigs Boiler.	Gen. M. C. Meigs' Little Giant Boiler. Results divided by 0.83.	Babcock and Wilcox Boilers.
	Utah.							
75	Weber, Chalk River, Summit Co.	10.	....	....	....	4.73	3.79	....
	Dakota.							
76	Lignite, Fort Stevenson	6.2	....	....	....	4.03	4.47	....
	Montana.							
77	Chestnut Mine, Rock Creek Canon	32.4	....	....	....	6.07	6.15	...
	California.							
78	Pittsburg, Mt. Diablo Mine, Somersville	11.	....	....	....	5.05	4.34	...
	Pacific Coast Brown Coals.							
79	Wahsatch Range, Mt. Diablo, Cal. Coos Bay, Oregon. Seattle, W. T. Av'ge.	13.18	....	Isherwood. 5.99	....	....	....	....
	Oregon.							
80	Eastport, Coos Bay	8.8	....	....	....	5.24	5.13	....
	Washington Territory.							
81	Brown Coal, Bellingham Bay	23.48	....	6.13	....	....	....	....
82	Seattle screenings	13.4	....	....	...	....	....	6.86
83	" " wet	10.7	....	....	....	....	....	7.46
84	" lump	9.5	....	....	....	....	....	6.68
	Vancouver's Island.							
85	South Wellington, Departure Bay	8.2	....	....	....	7.59	7.07	....
86	Nanaimo, Chase River	13.2	....	....	....	7.30	6.60	....
87	Wellington, Departure Bay	9.4	....	....	....	6.71	6.69	....
88	" screenings	18.3	....	...	...	....	....	7.89
89	" lump	13.8	....	....	....	....	....	9.02
90	East Welli'gton, screenings	16.8	....	....	....	....	....	7.80
91	Brown Coal, Nanaimo	12.7	....	7.36	....	....	....	....
	New South Wales.							
92	Wallsend, Sydney, Newcastle	8.8	....	....	....	....	7.11	....

Table I.—Concluded.

BEST PENNA. ANTHRACITE PERFORMANCE FOR COMPARISON.

NAME OF COAL AND LOCATION OF MINE.	PERCENTAGE OF REFUSE BY BOILER TEST.	PERCENTAGE OF VOLATILE MATTER BY ANALYSIS.	POUNDS OF WATER EVAPORATED PER POUND OF COAL, FROM AND AT 212°.				
			Scheerer-Kestner and Meunier-Dollfus, Elephant Boiler.	Prof. W. R. Johnson. Two-Flue Boiler.	Gen. M. C. Meigs. Meigs Boiler.	Gen. M. C. Meigs' Little Giant Boiler. Results divided by 0.843.	Babcock and Wilcox Boilers.
Forest Improvem't, Schuylkill Co.	7.0	....	....	10.25	....	....	....
Forest Improvem't, Schuylkill Co	20.6	....	....	....	9.37	....	....
Forest Improvem't, Schuylkill Co.	13.5	....	....	....	....	10.29	....
Lea Colliery, Wilkesbarre.	11.0	....	....	....	....	....	10.52

Table II.—Analyses of Bituminous Coals.

Corresponding Number in Table I.	Name of Coal.	Carbon.	Hydrogen.	Nitrogen and Oxygen.	Moisture.	Ash.	Fixed Carbon.	Volatile Matter.	Authority.
	Contin't of Europe.								
1	Ronchamp	76.23	4.06	1. 5 91	....	12.8	58.01	23.19	Kestner & Dollfus.
2	Friedrichsthal	67.81	4.19	0.5 13.8	1.	12.7	47.51	33.79	"
3	Duttweiler	71.25	4.1	0.5 9.15	1.75	13.25	44.51	32.19	"
4	Louisenthal	64.69	3.94	0.5 15.02	3.87	12.38	49.19	38.42	"
5	Altenwald	69.3	4.26	0.5 9.9	2.54	13.5	54.62	31.86	"
6	Heinitz	70.33	4.3	0.5 11.51	1.79	11.57	54.45	33.98	"
7	Sulzbach	74.36	4.43	10.75	....	10.46	....	....	"
8	Von der Heydt	73.03	4.46	12.05	....	10.46	....	....	"
9	Blanzy, Montceau	70.50	4.69	14.53	....	10.28	....	....	"
10	" Anthracite	68.79	3.73	6.53	....	20.95	....	....	"
11	Crensot	86.74	3.95	4.94	....	3.63	....	....	"
	England, Scotland and Wales.								
12	N'wc'tle, Av. of 18	82.12	5.31	1.35 5.69	....	3.77	....	....	Delabeche & Playfair.
13	Derbyshire & Yorkshire, Av. of 7	79.68	4.94	1.41 10.28	....	2.65	....	....	"
14	Lancashire, Av. of 28	77.90	5.32	1.30 9.53	....	4.88	....	....	"
15	Liverpool	....	....	....	.89	4.62	54.9	39.96	Johnson.
16	Newcastle	....	....	....	2.01	5.4	57.	35.83	"
22	Welsh, Av. of 37	83.78	4.79	0.98 4.15	....	4.91	....	....	Delabeche & Playfair.
23	Scotch, Av. of 8	78.53	5.61	1.00 9.69	....	4.03	....	....	"
24	Scotch	....	....	....	3.01	9.34	48.81	39.19	Johnson.
	Glasgow, Av. of Splint and Cherry.	82.06	5.47	11.19	....	1.28	....	....	Dr. Richardson.
	Boghead, Linlithgowshire	63.94	8.86	0.96 4.70	0.84	21.4	9.54	67.95	Dr. Penny.
	Nova Scotia.								
28	Pictou, Av. of 2	....	....	....	1.68	12.95	58.86	26.90	Johnson.
29	Sidney	....	....	....	3.13	5.49	67.57	23.81	"
	Pennsylvania.								
30	Dauphin and Susquehanna	....	....	....	.45	11.79	74.24	13.82	"
31	Lycoming Creek	....	....	....	.67	13.96	71.53	13.84	"
32	Blossburg	....	....	....	1.34	10.77	73.11	14 78	"
33	Quin's Run	....	....	....	.84	8.41	72.79	17.97	"
34	Karthaus	....	....	....	1.28	7.00	73.77	19.53	"
35	Cambria Co	....	....	....	2.46	9.15	69.37	20.52	"
36	Pittsburgh	....	....	....	1.4	7.07	54.93	36.76	"

Table II.—Continued.

Corresponding Number in Table I.	Name of Coal.	Carbon.	Hydrogen.	Nitrogen and Oxygen.		Moisture.	Ash.	Fixed Carbon.	Volatile Matter.	Authority.
44	Johnstown, Cambria Co.	....	....	....	....	0.79	8.07	77.90	13.24	Hunt and Clapp.
48	Castle Shannon, near Pittsburgh..	....	....	....	....	1.51	3.92	62.88	31.69	"
	Pittsburgh, "Cincinnati Smoke-prevention tests"....	....	....	....	....	2.31	3.04	61.03	32.75	B. Kniffler
	Maryland.									
51	Av. of 5. Free-burning bit'm'n's.	....	....	....	....	1.25	9.49	75.45	14.21	Johnson.
52	Cumberland.....	80.55	4.50	1.08	2.70	1.75	8.25	....	....	Isherwood.
	Virginia.									
53	Av. of 10 Coking coals, near Richmond.	....	....	....	....	1.62	10.58	58.30	30.36	Johnson.
	Illinois.									
64	Staunton, Fine nut	....	....	....	....	6.27	10.32	26.30	57.11	Hunt and Clapp.
	Pacific Coast.									
79	Av. of 4 Brown Coals.....	50.05	3.85	0.91	13.65	16.82	13.18	....	....	Isherwood.
	Washington Ter'y.									
81	Brown Coal, Bellingham Bay.....	49.60	3.39	0.83	8.96	12.52	23.48	....	....	"
	Vancouver's Isl'nd.									
91	Brown Coal, Nanaimo.....	59.68	4.08	1.00	10.78	10.26	12.74	....	....	"

Table III.—Evaporative Power of Bituminous Coals.—Tests with Babcock & Wilcox Boilers.

No.	Date of Test.	Place of Test.	Name of Coal.	Duration of Test.	Average Temperature of Feed—Degrees.	Average Steam Pressure—Pounds.	Grate Surface—Square Feet.	Heating Surface—Square Feet.	Pounds of Coal Burned.	Percentage of Refuse.	Coal Burned per Square Foot of Grate—Pounds.	Water Evaporated—Pounds.	Water Evaporated per Sq're Foot of Heating Surface per Hour—Pounds.	Water per Pound Coal from and at 212 Degrees—Lbs.	Water per Pound Combustible from and at 212 Degrees.	Rated Horse Power.	Horse Power Developed.
1	Oct. 30, 1882.	London, England.	Welsh	13½ hours.	130	67	40.	1679	3,360	7.5	6.3	34,800	2.07	11.53	12.46	146	96
2	Nov. 14, 1882.	Greenock, Scotland.	Scotch	3 hours.	156	36	25.	1403	1,344	7.0	13.7	14,426	2.78	11.52	12.38	122	129
3	Dec. 15, 1882.	Peacedale, R. I.	Anthracite screenings, 2790 lb. / Powelton, Pa., Bituminous, 11,400 lb.	10¼ hours.	38	77	60.	3126	14,359	8.8	17.6	133,096	4.32	11.32	12.42	272	448
4	July 19, 1882.	Cincinnati, Ohio	Pittsburgh fine slack	4 hours.	74	52	33.7	1679	7,365	12.3	21.9	51,459	4.47	8.12	9.29	146	250
5	Sept. 7, 1882.	" "	Pittsburgh, 3d Pool lump.	10 hours.	132	64	43.5	2760	12,000	4 8	27.5	112,663	4.76	10.47	11.00	240	419
6	March 12, 1883.	Pittsburgh, Pa	Castle Shannon, near Pittsburgh, nut	6¾ hours.	37	95	69.1	4784	13,000	13.	27.9	95,286	3.63	8.96	10.29	416	556
7	Mar. 13–15, 1883.	" "	Castle Shannon, near Pittsburgh, lump.	25¼ hours.	37	95	69.1	4784	39,900	9.	22.9	330,533	3.44	10.13	11.13	416	504
8	Mar. 15–17, 1883.	" "	Castle Shannon, near Pittsburgh, ⅝ nut, ⅝ lump.	42½ hours.	37	95	69.1	4784	83,524	10.5	27.9	683,956	4.13	10.00	11.17	416	570
9	Sept. 18–23, 1882.	Chicago, Ill	Illinois "run of mine."	6 days.	190	75	....	1196	10,675	....	....	95 940	1.41	9.49	....	104	54
10	Jan. 8–10, 1883.	" "	Indiana block, "very good."	3 days	190	85	....	1196	11,150	....	....	99,676	2.95	9.47	....	104	111
11	Dec. 14, 1882.	Springfield, Ohio	Jackson, Ohio, nut.	8 hours.	117	90	48.	3358	12,398	9.6	32 1	97,021	4.11	8.93	9.88	292	465
12	May 2, 1883.	" "	Staunton, Ill., fine nut.	8 hours.	155	97	60.	3358	12,034	17.7	25.1	55,614	2.27	5.09	6.19	292	246
13	May 28, 1883.	Johnstown, Pa	Johnstown, fine slack	7¾ hours.	90	80	51.	3126	6,175	25.1	15.6	50,906	2.44	9.59	12.80	272	246
13	Febru'y 10, 1883.	San Francisco, Cal.	Renton screenings	5 hrs. 50 min.	56	106	21.2	1564	3,910	13 8	31.5	22,366	2.95	6.88	7.98	136	151
15	" 12, "	" " "	" " "	6 hours.	57	99	21.2	1564	4,346	23.	34.8	24,282	3.12	6.71	8.71	136	161
16	" 13, "	" " "	Wellington screenings	6 hrs. 30 min.	57	110	21.2	1564	3,740	18.3	27.	21,547	2 93	7.89	9 66	136	150
17	" 16, "	" " "	East Wellington screenings	6 hours.	57	107	21.2	1564	3,740	16.8	29.3	24,282	3.11	7.80	9.38	136	160
18	" 17, "	" " "	Black Diamond screenings	5 hrs. 58 min.	57	107	21.2	1564	4,640	19.3	36.4	24,282	3.11	6 29.	7.80	136	160
19	" 19, "	" " "	Seattle screenings	6 hrs. 24 min.	58	116	21.2	1564	4,260	13.4	31.3	24,282	2.91	6.86	7.92	136	150
20	" 20, "	" " "	Wellington lump	6 hrs. 19 min.	59	119	21.2	1564	3,777	13.8	28.2	28,329	3.52	9.02	10.46	136	171
21	" 21, "	" " "	Seattle screenings, wet	6 hours.	60	119	21 2	1564	3,915	10.7	30.7	24,282	3 11	7.46	8.35	136	160
22	" 22, "	" " "	Cardiff lump	6 hrs. 47 min.	60	114	21.2	1564	3,863	11.7	26.7	32,376	3.69	10.07	11.40	136	189
23	" 27, "	" " "	" "	7 hrs. 23 min.	62	117	21.2	1564	4,032	19.1	25.6	32,376	3.35	9.62	11.89	136	174
24	" 28, "	" " "	South Paine lump	6 hrs. 35 min.	62	118	21.2	1564	4,059	13.9	28.9	30.315	3.53	8 96	10 41	136	182
25	March 1, 1883.	" " "	Seattle lump	6 hrs. 5 min.	63	118	21.2	1564	4,420	9.5	34.1	28,329	3.57	7.68	8.49	136	184

BALANCED VALVES.

BY

C. C. COLLINS.

I DO not propose to give an exhaustive statement of the various styles of "balanced valves," but simply to present a few facts in my experience with what may be called the "Pressure Plate Balanced Valve." I suppose, without doubt, the "piston valve" patented by D. T. Davis is the mostly perfectly balanced of any slide valve; but, unfortunately, like everything else, it is subject to wear,

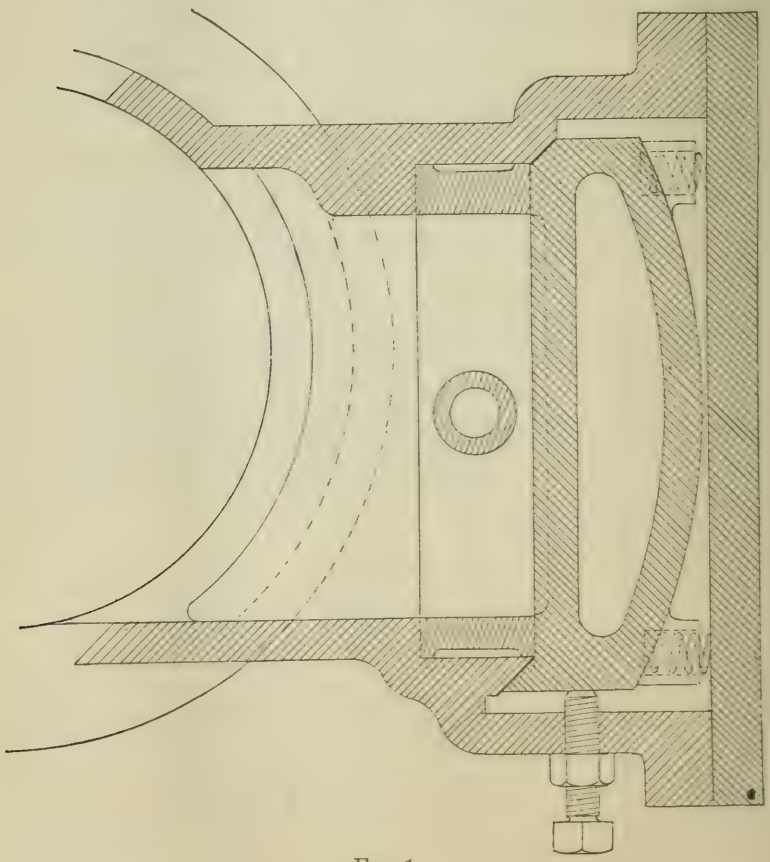


FIG. 1.

and when worn it leaks and becomes very wasteful of steam. A great many devices have been resorted to to keep the *rings* in contact with the wall of the valve chamber, but none have proved successful. Probably the best method is to bore the valve chamber as accurately as possible, make a good fit of a "plug valve," and when worn so as to leak, then re-bore and fit new valves.

In these sketches I have shown, first, a section through valve seat, valve and pressure plate of what is known as the Porter-Allen valve. This shows the method of holding the "pressure plate" so as to allow the valve to move freely between it and valve seat, and yet not permit the leakage of steam. This, you will observe, is

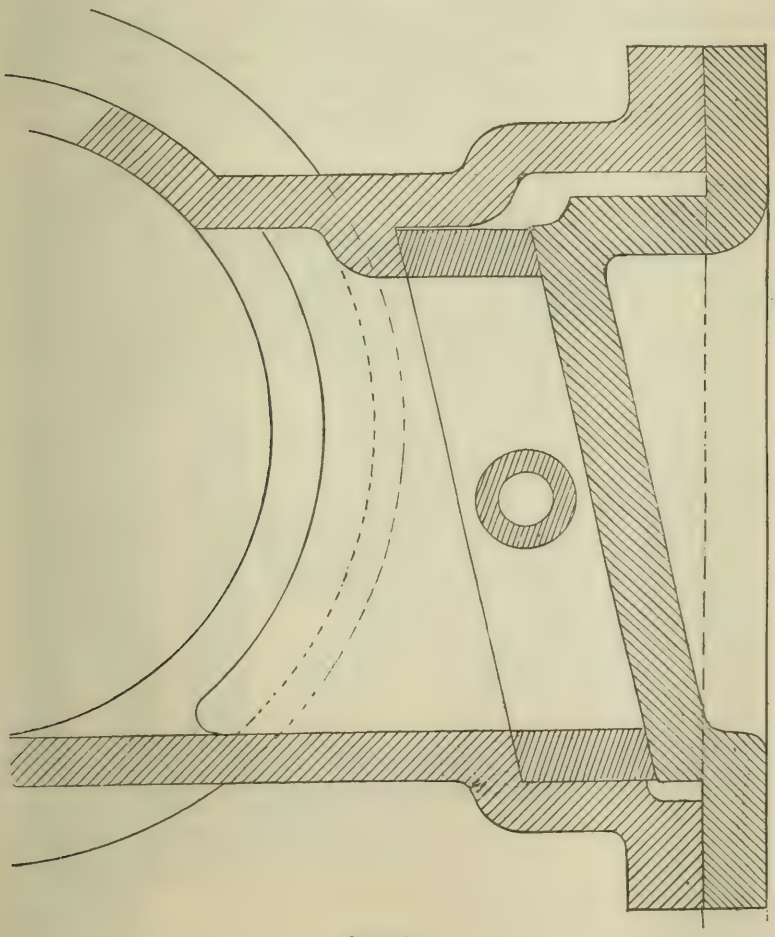


Fig. 2.

done by means of the inclines at the top and bottom of valve and set screw passing through bottom of steam chest. These inclines are at an angle of 45°. The plate is held against them by springs, and by the pressure of steam at back.

If the plate be raised by means of the set screws, it will be forced out from contact with valve by means of the inclines. This device has proved effectual, subject however, to derangement by unskillful adjustment.

Sketch No. 2, is a device of John F. Allen, and is used by Hewes & Phillips, of Newark, N. J., in the Allen High-speed Engine which they build. You will notice that the valve seat is on an incline, and that the "pressure plate" is one piece with the steam chest cover, and comes in contact with the surface of valve. This can only be adjusted by slacking the nuts, which hold the cover in place, and moving it up or down, involving great risk of misadjustment. It has also another bad feature—not allowing any

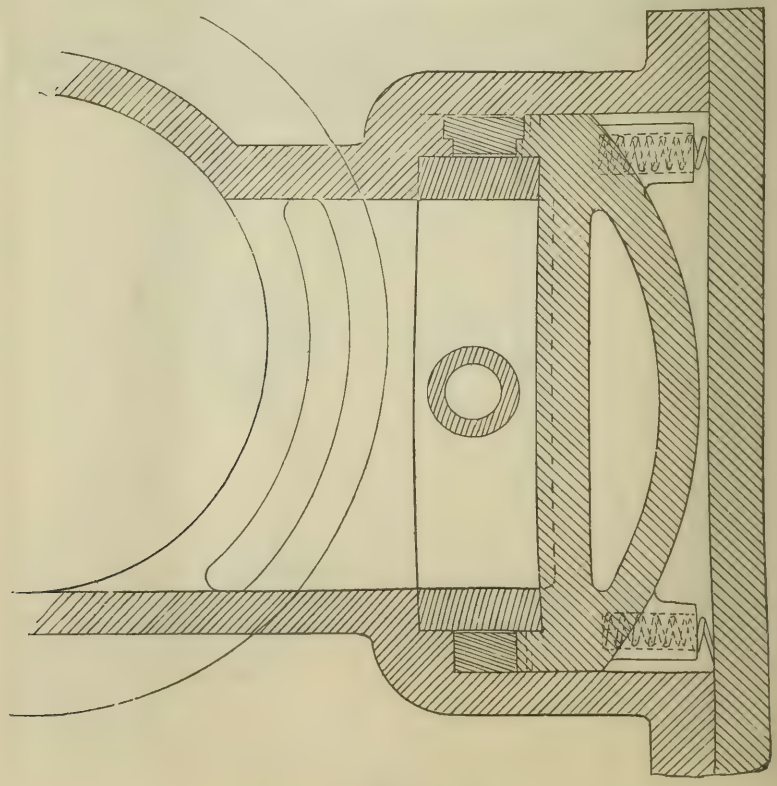


Fig. 3.

lift of the valve should water be trapped in cylinder. I was in the employ of this firm when their first engine of this style was in progress of construction, but left them before it was completed, but have been informed that they were obliged to put relief valves on the cylinder after it was in operation.

Sketch No. 3 is a modification of the "pressure plate" and valve as used by Prof. Sweet. Prof. Sweet uses a plain strip between the "plate" and valve seat at top and bottom, so as to allow free movement of valve between them. I make these strips long wedges, and adjust by means of set screws through walls of steam chest. The only objection to this is, that it allows of manipulation by an unskillful engineer. In a large majority of cases it has proven very satisfactory. I have also used the plate by simply letting it bear against shoulders in steam chest, properly arranged and scraped to a good fit.

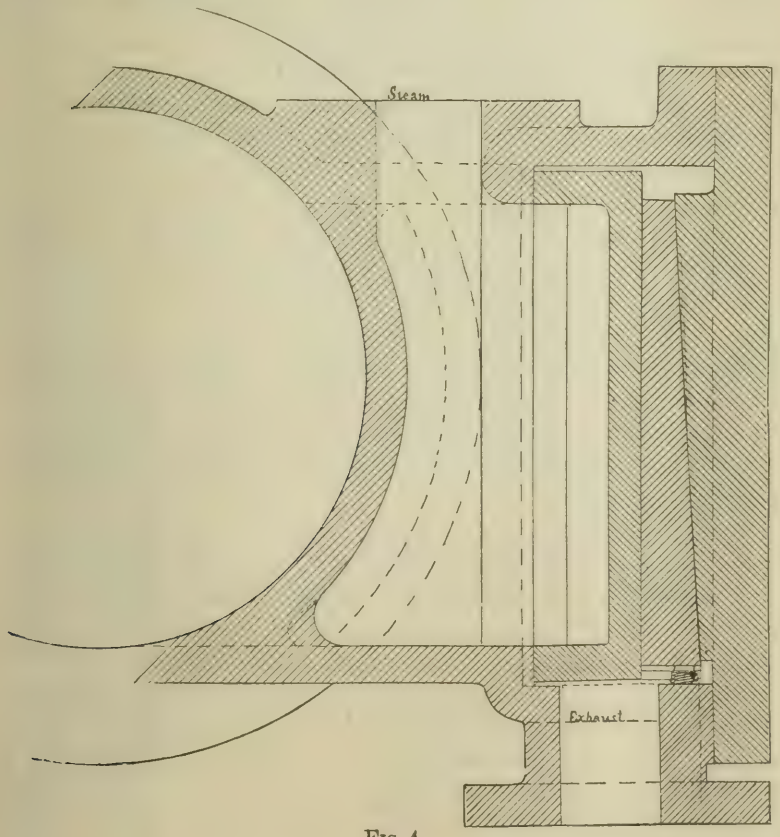


Fig 4.

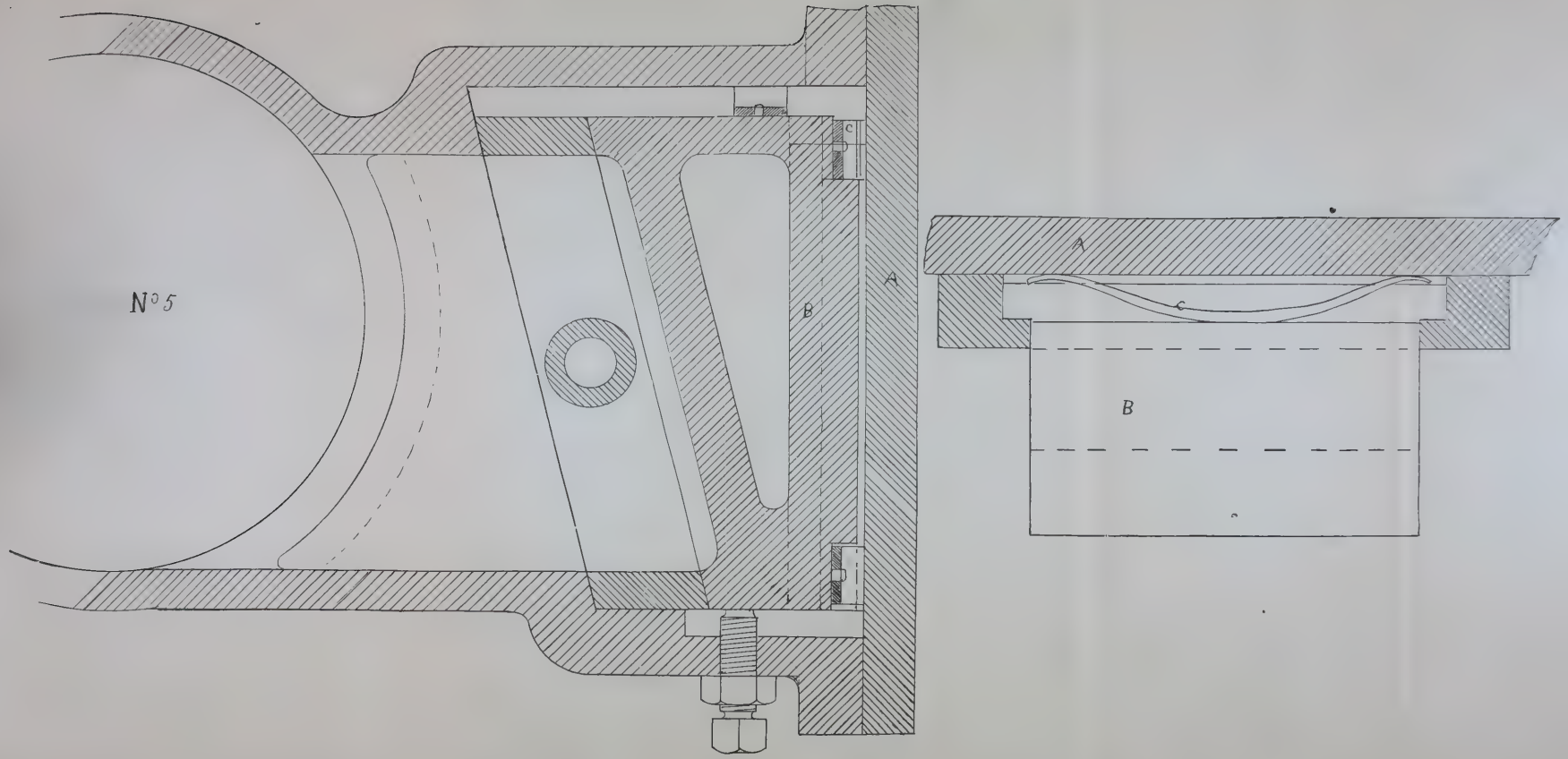
There is an engine in this city (Cleveland) which has its steam chest on top of cylinder; the valve is 18″ × 23″. It was desired to relieve the enormous load due to so large a valve. I put in a "pressure plate," with the long, thin wedges at the sides, adjusted by set screws at each end. To get depth of chest to accommodate this "pressure plate" I cast a thick copper gasket to go between top of steam chest and cover. This arrangement has given entire satisfaction.

Sketch No. 4, is an arrangement which I put into an engine of 10″ bore and 16″ stroke. You will notice that the steam is admitted into the interior of valve and exhausts into steam chest and passes out of bottom of same. The valve is provided with a wedge at back to keep valve to its seat. This is subject to the same objection as the Allen valve, and the cylinder is provided at each end with a relief valve. This engine has been running continuously night and day since October, 1881, and has never given any trouble.

Sketch No. 5 is an attempt to construct a valve which shall have all the advantages of Mr. Allen's without any of its drawbacks. It is adjusted by setting the valve seat at an angle and introducing a wedge-shaped "pressure plate" between valve and steam chest cover; this plate has lips which rest in channels or grooves, formed on inside of steam chest cover in such manner that a space is left between plate and cover, and yet the plate cannot bind the valve to hinder its free movement; by this means the valve can lift from its seat should any water be trapped in cylinder. This "plate" is adjusted by means of set screws at the bottom. This valve arrangement was placed in an engine of 18″ bore and 36″ stroke, and was subject to very hard usage, so that it has never given perfect satisfaction, owing to its being constantly adjusted by the attendants, and the character of some of these may be seen by the following incident:

I found, on going into the engine-room one day, the crank pin was warming, and asked the engineer the cause. *He did not know*, but I found he had removed the automatic oiler and filled the cavity in crank pin with hard soap, saying, "he had heard that soap was a good lubricant."

In investigating the causes why so frequently this class of valve will run well for a long time and then, when adjustment is attempted, it is almost impossible to secure good results until quite a period has elapsed after the adjustment is made, I have found that where the movement of pressure plate for the purpose of ad-


N°5
A
B
C
A
C
B

justment is *across* the valve, it disturbs the agreement between the surfaces of plate and valve. After running a while it will be found that both valve and plate are worn uneven, frequently in ridges, and so any movement brings into bearing new parts, and leaves open spaces where steam will pass. When, however, the plate is moved directly in upon the valve, as in the valve shown in Sketch No. 3, or in Prof. Sweet's method, this difficulty is not encountered. The best results are obtained when the pressure plate is so arranged that it cannot be manipulated by the person in charge of the engine, but when it is found necessary from any cause to readjust, it should be put into the hands of competent men, who should put it in the same condition as at the first.

I have also found that it will not do to send engines out with "pressure plate balanced valves" which have never been scraped after being heated under steam, as, no matter how carefully they may have been fitted in the first place, both plate and valve will distort, and hence trouble ensue, and sometimes the process of scraping to a fit has to be repeated several times before a fit will be obtained which will remain. Again, trouble has arisen from the weakness of the plate; this should be of the most rigid character, so that when under steam there may not be the least tendency to spring in centre and so bind the valve.

If these precautions are observed, this class of valve will satisfy all reasonable expectations.

ON STANDARD CAST-IRON FITTINGS.

BY

WILLIAM J. BALDWIN, NEW YORK.

The absolute and positive necessity for uniformity in cast-iron fittings for wrought iron pipes, prompts me to take an interest in a work which evidently was commenced by the late Robert Briggs, of Philadelphia, a member of the Institute of Civil Engineers, and known professionally to many here.

In a posthumous paper ("American Practice in Warming Buildings by Steam") and I believe his last contribution to Science, which was read before the Institute of Civil Engineers in England (Session 1882–83, Part I.), he gives many valuable *data* relating to wrought iron pipe-threads and fittings and introduces a scale for dimensions of cast-iron fittings which does away with needlessly complicated formulæ, giving by simple straight lines the necessary measurements for laying out all sized fittings—(Elbows or Tees) from $\frac{1}{8}$th of an inch to 8 inches, inclusive.

He had much to do with giving character and form to the present merchantable fittings and valves, and deplored—for none knew better than he—the condition into which competition in prices was degenerating a branch of industry which may be said to be purely American.

Wrought iron pipe is standard in size because it cannot well be otherwise, and the only way it can be varied is in the thickness of the iron from which it is made, as the outer diameter must be sufficiently exact to fit within the guide-bushings of the stocks and dies and at the same time give a full thread—this fact always keeping the pipe sufficiently near the standard to be practical.

But with fittings, more especially cast-iron ones, the only thing which can be said to be standard about them, is the thread—and *it* is not standard with many makers, except in so far as the diameter at the outer edge of the thread is concerned—the rest of the thread being parallel.

When the cast-iron fitting was first made—wrought-iron, brass, and malleable iron being previously in general use—it was supposed from the generally considered friable nature of the metal, that the

fittings would be easily broken—hence sizes and proportions were adopted which were positively ample and which later experience proved to be heavier than was actually necessary for ordinary purposes.

This led to a reduction to sizes and shapes, which, though different manufacturers varied somewhat, were, and are now, pronounced "good fittings"—meaning that they were sufficiently heavy,.so as not to split with ordinary manipulation and called for no anxiety on the part of the workman about the permanency of his construction.

But these fittings, when at their best, were alike only in their *nominal distinction*—their length and radii being as various as there were manufacturers; and not infrequently different patterns by the same maker were in the market.

Gradually, as the manufacture became more important, *prices* which at first gave an ample profit, and which called for no retrenchment on the part of the maker, were reduced by those who were eager to increase their sales, and which, as long as they put an equally good fitting on the market, were perfectly justified by the laws of trade. But the result was as should be expected with a commodity that had no *standard quality.*

Manufacturers—some of them against their judgment—began to lighten their fittings, so as to be able to meet the market at a profit. The general result was—as light a fitting as would possibly stand screwing up, leaving no factor for safety.

But this was not all. Fittings had to weigh less still to make a profit on them, and as they had reached the minimum in thickness, they had to be shortened in radius—in what is called "the length from the centre,"—the length of the "hub," and the length of the inside of the hub in which the thread is cut, until the inside thread of a fitting is shorter than the length of an ordinary thread on a pipe, allowing the end of the pipe to screw past the thread in the fitting. In fact, the fitting may be said to have reached the ultimate degree of attenuation and stunting it will bear.

The use of the "straight tap" is also to be condemned.

With fittings of certain sizes (below 2″) it is found that they can be molded and cast sufficiently accurate so that they can be tapped without reaming; but it has also been found that the "skin" of the casting spoils a tap rapidly. This led to the use of a long tap with parallel sides, which can be ground backward from the point —the point always forming a reamer below the first tooth of the

tap—and as the tap is fed to its work by a lead screw of corresponding pitch, it can be forced into the fitting.

The reason why fittings should not be threaded with a parallel tap is obvious, and requires no further comment from me; but I will say, another inducement to use the "straight tap" is the decreased power necessary to operate it.

The objections to present fittings may be summed as follows:

I. The greater part of them are too light.

II. The radius is frequently too short.

III. Elbows, tees, and crosses of the same maker have generally *not* the same length from ends to centres.

IV. Fittings of the same denomination from different makers, do not agree in length and radius.

V. Many fittings are tapped straight.

VI. Inaccuracy in the shape and taper of threads.

VII. A tee or cross will not go *in* where an elbow came *out* without changing the length of the pipes.

VIII. Tees of a given *prime* denomination have not the same lengths.

IX. Crosses of a given *prime denomination* have not always the same length.

X. Tees and crosses, in their *secondary denominations*, have not the same length from centres to ends of branches, for the same *primary* denominations, nor do tees and crosses agree with each other.

XI. A reducing elbow has not the same measurements as a reducing tee of the same general denomination.

XII. There is no simple method by which a person cutting pipes can always find what has to be allowed, when he is given centre measurements, if he has not the fittings in his possession.*

RECOMMENDATIONS FOR STANDARD FITTINGS.

I. That a minimum thickness of metal be established for the different parts of a fitting, according to its *prime* denomination, above

* It should be here explained, for those not versed in the technicalities of the fitting trade, that in calling or denominating a fitting, the way a fluid will flow for *distribution* must be borne in mind, and the sizes of openings given in the order of their magnitude, commencing with the greatest and going straight through the fitting in the direction of the flow, first. The largest opening of a fitting is the prime denomination: with a single exception in what is called a "bull headed tee"—one whose side branch, or opening, is the largest: when the smaller sizes in a direct line are mentioned first.

which makers may go if they desire, but below which the fitting *will not be standard.*

II. That the radius of a fitting be fixed, and that it shall bear some *common relation* to the diameter of the pipe.

III. That elbows, tees, and crosses of the same prime denomination shall have the same lengths from *centres to ends of hubs.*

IV. That the length of a fitting from its centre to the end of the hub bear some *common relation* to the *diameter* of the pipe.

V. That a standard fitting must have a standard weight, below which it *must not* go.

VI. That all fittings be tapped with a *taper* thread of 1 in 32 to the axis of the openings — $\frac{1}{16}$ of an inch to one inch in length of thread—and that the present established method, which is not accurate, though capable of maintaining a practical uniformity in diameters, be retained until such time as methods founded on the "Standard Gauge System" be adopted.

VII. That a minimum length of thread be established for fittings in proportion to the size of the pipe, below which they will not be standard.

The use of scales for fitting and valve-making—one of which, for elbows and tees, is represented in the accompanying cut—was due to Robert Briggs.

His practice was to have these scales engraved or heavily scratched on brass or copper plates from which the dimensions of fittings of any desired size could be taken at once with a dividers by the pattern-maker, without tedious calculation, and without having to furnish him with working drawings, and preventing a possibility of change in dimensions or design.

The explanation of the scale I will give in his own words, namely:

"In regard to the construction of the scale shown in the diagram, the ordinates, though here headed for convenience with the nominal inside diameters of the tubes, are spaced from the zero point at horizontal distances (*half* full size) equal to the actual outside diameters of wrought iron pipe. Of the slant lines, only two pass through the origin or zero point: namely, the line for the internal radius *R* of the back of the elbow, and the line giving the dimension *A*, which is exactly half the radius *R*. Of the remaining lines, those giving the three dimensions *B*, *D*, *C*, intersect the base line a little to the left of the origin or zero point, which means that each of the three dimensions given by these lines contains some small increment in excess of the dimensions that would be strictly proportional.

For instance, with regard to the thickness *C* at the back of the elbow, it is evident that, if the metal in any casting, whether small or large, thin or thick, were truly homogeneous throughout both its skin and its interior portion, this thickness should then be strictly proportional to the diameter or radius of the bore; but for small castings a certain allowance of extra thickness is needed, in order to insure soundness, as well as to compensate for the increased brittleness of thin cast-iron. There will, however, be some size of fitting, for which the normal strength of metal may safely be assumed, and for which, therefore, no extra thickness will be needed. On this assumption the thickness for the largest size is set out at the end of the scale farthest from the origin; while nearest to the origin is set out the thickness proper for the smallest size, in which the increment is at its maximum; and the slanting straight line drawn between these two extremes gives for intermediate sizes an increment which varies inversely as the diameter or radius. Needlessly complicated formulæ, involving higher or lower powers of the diameter, are thus replaced by the simple straight line. In the two bottom lines, *L* and *F*, pertaining to the screwed portions of the fitting, which are a function of the pitch, the irregularities of slope are due to the fact already commented upon, that the pitch of the screw thread for different diameters of tube proceeds by a medley of arbitrary jumps, instead of by a steady progression concordant with that of the tube diameter."

Similar scales furnish dimensions for valves and other fittings, but as the question under consideration—elbows, tees and crosses—is fully covered by this scale, if the fittings are to be made of a uniform length, they need not be considered now.

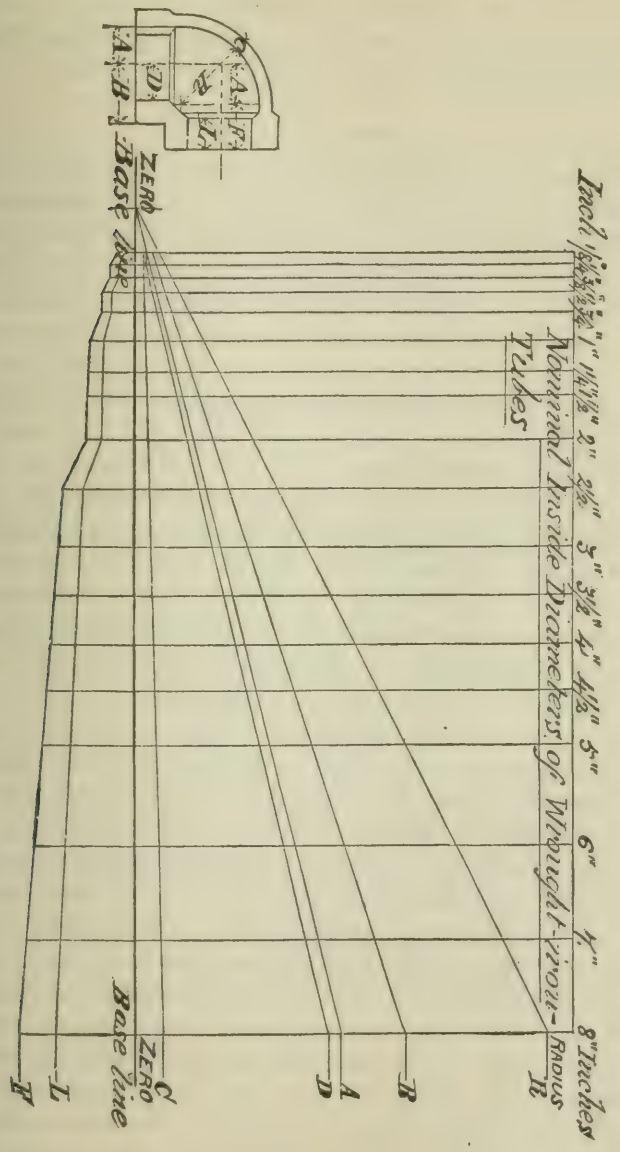
It should be noticed the distance from *F* to *A* establishes the length of the fitting from centre to end of hub—the first consideration in a standard fitting,—while from the *base line* to L establishes the length of the thread; *C* giving the thickness of the shell of the fitting, and the difference between *D* and *B* determining the thickness of the hub.

[At the meeting, full size drawings (1″, 2″, 3″, 6″ and 8″) made by this scale were exhibited.]

The questions to be determined are:—Are these sizes suitable? or, if not, what is suitable? Is the thickness *C* too great for large sizes? and Is the difference between *D* and *B* great enough for the *one-inch elbow?*—and kindred questions; and determine a new position for the ordinates.

The reason why I introduce this scale to the notice of the Society is, should a committee undertake to establish standards for fittings they will meet with both opposition and welcome from manufacturers, some of whom may be anxious that their method should be adopted, though subject to modification in dimensions. But even should a method be found in use equal to the one here described, the fact of adopting it or making it a basis of *the standard*

would be a probable cause of dissatisfaction to those in the business, and perhaps be the means of making a committee's work abortive.



This is why I select the *method* (though I must not be understood to select the dimensions unqualified) of an engineer who is

no longer among us and to whose memory and engineering skill we will raise a *tablet* more lasting than a monument by a recognition of his diagram.

If it can be made compatible, malleable-iron fittings should also agree with cast in their dimensions as to lengths, etc.; the thickness being determined by the work for which they are intended.

DISCUSSION.

Mr. Le Van.—I would like to say, in connection with this matter, that there was a committee of the Franklin Institute in existence for about four years on this subject, and the difficulty was to get the manufacturers to accede to anything, so as to establish a standard. Each one thinks that he has the best, and the result has been that we were unable to come to any conclusion, from that fact alone.

Mr. Barr.—Mr. President, I have had a great deal of experience with steam fittings, and I think others who have had occasion to use steam fittings will agree with me in this: that, for elbows especially, the fittings are too small, and that is one of the defects which I think is quite as important in considering this question as the matter of strength and the threads and the other things that were named. Now, when we come to take the embarrassment which naturally enough comes from buying fittings in an open market (and no manufacturer can afford to do that thing), he will soon have to settle down to some one set of fittings.

Several years ago I had occasion to design a series of engines which were to be built in large quantities, of which, I suppose, there are some 1,500 or 2,000 now running. They were turned out at the rate of three or four hundred a year, but not knowing where these engines had to go, the pipes and the fittings had to be gotten out entirely by drawings, the distance from the centre of the boiler to the centre of the engine being marked on the drawings. Perhaps these fittings would be cut and boxed and lie in the warehouse six months before shipment, so that in a manufactory of that kind it is very important that we know exactly what we are going to get, because we do not know where they are going. Now, for small engines using ordinary slide valves, in which the initial pressure in the cylinder would probably not be over two-thirds of that of the boiler, and in which the ordinary governors are used and the steam thereby wire-drawn, I do not know that it would make so very much difference about the size of the fittings, because

the pressure is reduced more at the governor than it is at the bend. But when we come to take automatic engines, and especially engines of large size, then the real difficulty to the manufacturer comes in. It has been my practice for some years to use the ordinary fittings up to four inches, and above that to make them. One reason why I would not use a fitting such as has been shown here, is simply because the turn is too abrupt. And another thing: I would not use a tee that would be made according to that scale reversed. It has been my practice for some time in making tees for large engines to make them like Fig. 1, using the same scale for the elbows, as shown by the dotted line. I cannot give you the dimensions, but you will readily see the difference between the two forms in a flow of steam, especially when you guarantee that you will get an initial pressure in the cylinder only one pound less than that in the boiler, with the engine one hundred feet away. That can be done very easily if you get the particular shaped bends and tees. And if there is to be any further discussion on that paper, I should like to know if there are any here who have experimented with the actual loss in pressure due to these abrupt bends.

Mr. Baldwin.—I suppose the gentleman knows that my proposition was not to accept that elbow. My elbow is simply drawn by that scale (Robert Briggs' method). I want the *method* of the scale accepted, and the committee will determine what the fitting will be by new ordinates in the diagram. The engine industry is a large one; but there are other industries that use pipe and fittings in greater quantities than the engine industry that have to be considered in this question. There are steam fitters, gas fitters, and water men that all use elbows. The elbows must fit the standard pipe, and you can make the radius as long as possible, but you must not make it so long that the fittings can be used only by the engine manufacturers. He can make special fittings, or he can bend his pipes in the fire if he wants to, and make his radius as long as he likes. But the main thing is the question of uniformity, so that all elbows and fittings of the same denomination will be alike.

Now, there are fittings in the market for any one that wishes to go into it, but what are many of them like? A man says he is selling a one-inch elbow for so much money. They connect two pipes together (after a fashion). Another sells a one-inch elbow which weighs twice as much, and has more radius, and will connect two pipes properly, but he can get no more money for it, as a gen-

eral thing, than the man that offers the light elbow. Competition may be the life of trade, but it is the death of cast-iron fittings without a standard. This has got to be taken into consideration in establishing a standard elbow or fitting. In this method of showing two elbows (Fig. 1, drawn by Mr. Barr on the blackboard), do you mean that the lengths shall be the same as proposed standard fittings?

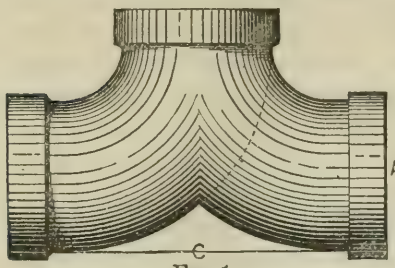


Fig. 1.

Mr. Barr.—That is intended for a very large pipe. When you get to making those tees from six to twelve or fifteen inches in diameter, you don't want to carry that line (*C*) straight across.

Mr. Baldwin.—If the flow is straight through the fitting, you do; but there are many industries to be considered, and any one may make special fittings. But length of fittings from end to centre can be the same as the trade fittings if you please, so that a man ordering them knows they are standard in this respect.

Mr. Barr.—That is not what I am talking about. I am talking about fittings specially adapted for large automatic engines, in which there must be no difference in pressure between the steam chest and that in the boiler, no matter what the length of intervening pipe may be.

Mr. Baldwin.—To meet your difficulty I would make them in the way shown in Fig. 2. The measurement from centre to end will still remain the same; but the fitting will be chambered. Again, to get nearly initial pressure in the cylinder, why not use a large supply at least as far as the throttle valve.

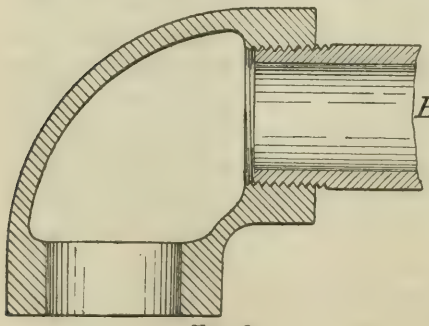


Fig. 2.

Mr. Le Van.—Why chamber it? (meaning the fitting).

Mr. Baldwin.—There is a fitting now, or there has been a fitting in the market, which was straight on the outside, like the illustration, which gave good results. Of course, you may make that by the same scale.

Mr. Le Van.—How about the expansion of volume?

Mr. Baldwin.—Oh! the volume don't expand under constant pressure.

Mr. Le Van.—You put water through an elbow like that and one that is straight through—not chambered, as shown—and see if you don't find a difference in the flow. I don't know why we should change the Morris, Tasker & Co. style of fittings, when for the past twenty years I have been using them up to a sixteen-inch diameter pipe on Corliss engines, with a difference of only two pounds between the boiler pressure and the initial pressure of the cylinder. Now, any additional length of elbow would not add to that initial pressure.

Mr. Barr.—But it will make a difference in the flow?

Mr. Le Van.—No, sir; not in the least. If I can get in a twelve or sixteen-inch pipe with only two pounds of difference between the boiler pressure and the initial pressure of the cylinder, what better can you do?

Mr. Barr.—I can do one pound better. (Applause).

Mr. Baldwin.—Gentlemen, it is not a question of changing the fittings—it is a question of uniformity.

Mr. Le Van.—If Mr. Barr's proposed tees, as illustrated on the blackboard, are to be used by having the flow of steam or water from *A* and *B* through outlet *D*, it will be a proper and desirable fitting; but, if the flow is from *A* to supply *D* and *B*, it will not be a proper fitting, as the flow will be impeded by the projection at *E* as regards the supply to *B*, as is well known to all engineers. If the fitting was made straight on the line *C*, so as to remove the projection *E* on the inside, it would make a better and more desirable fitting. I have made and used fittings of six inches diameter and upward, of this pattern, and found them to give good satisfaction.

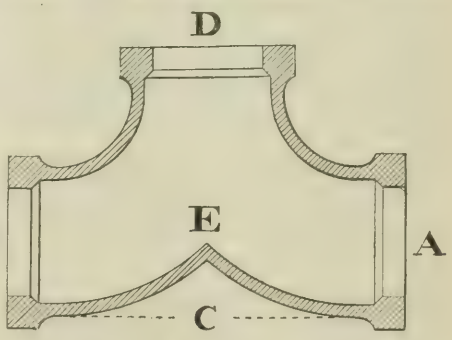


FIG. 3.

Mr. Baldwin.—I agree with Mr. LeVan. I cannot see how anything is to be gained by a hollow back *tee*, for usually two of the openings are outlets.

Mr. Le Van.—I admit that there are no two houses in the trade that make fittings exactly alike; but, if I send an order to any steam fitters in Philadelphia, and write it out, with dimensions marked from centre to centre of fittings, when I receive the pipes and put them together they will come together within a sixteenth of an inch. You cannot get these manufacturers to change their standards when they have millions of feet of pipe and fittings in actual use. When you have a good thing, why change it?

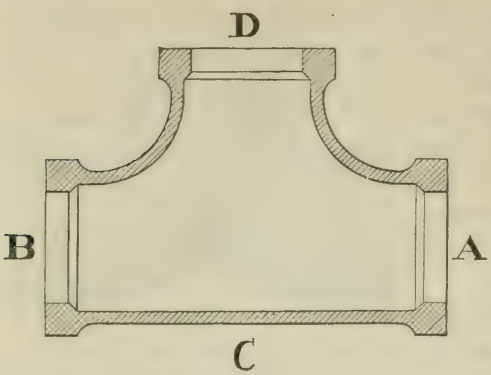


FIG. 4.

Mr. Baldwin.—For instance, if the Society can adopt the fittings of Morris, Tasker & Co. without modification or any other makers' fittings (Walworth of Boston, or Nason of New York, or Crane of Chicago), let it adopt them and try to induce the smaller dealers and others to adopt their standard. If there is a fitting with the indorsement of the Society, and a demand comes for a standard fitting, these manufacturers will find it to their interest to adopt it. The object of a standard fitting is to do away with the desire or the possibility of making light fittings, and thin and short ones.

Mr. Le Van.—You cannot control that.

Mr. Baldwin.—There was no trouble in establishing a standard in bolts and nuts. It was not a long time until the trades came to it.

Mr. Le Van.—We have not got to it yet. I bought some nuts in Philadelphia the other day, and they would not fit the bolts I had in stock, that were made within six months. (Laughter). The point I wanted to make is this: If Morris, Tasker & Co. have a standard set of fittings which is adopted by all the manufacturers in Philadelphia—and every one will admit that the interest in pipe and fittings is as large, if not larger, in the city of Philadelphia than in any other city in the country—they have a standard which is a good one. Why should we change that? All we could recommend would be that other dealers should come to that

standard. As I said before, I have been on a committee of the Franklin Institute for some three years, and I don't know how many letters we have written on this subject, but no one seems disposed to give up a standard that has answered their customers for years. All we could recommend was that all manufacturers should adopt the Morris, Tasker & Co. (Briggs') standard. I am sure no better styles and dimensions can be adopted than those of the above establishment.

The President.—It would appear to the Chair that so long as the Franklin Institute, which is a venerable and respected body, has had a committee on this subject, and has not accomplished anything in three years, that this Society can direct its attention in a more profitable direction. (Applause).

Mr. Le Van.—We would like to have some assistance from the Society. Probably its influence is greater than ours. We are a little old-fogyish, you know.

Mr. Baldwin.—The adoption by the Society of this scale of Robert Briggs as a standard will bring others up to that standard.

The President.—Of course, if the gentleman wishes, he can move the appointment of a committee later, which will bring out the views of the members of the Society on that subject, and perhaps that would be the best way to test the sense of the Society. It is not in order to make such a motion at the present time.

Mr. Walker.—I would like to ask one question relative to fittings, and taps for fittings. Is there any standard taper or size for pipe-fittings and pipe-taps? A few weeks ago we had occasion to put together some right and left hand fittings and pipes. I bought some right and left hand taps; but, unfortunately, we could not get them both of one make. We had a Pratt & Whitney right-hand tap and a Morris & Tasker left-hand tap. I found they differed a sixteenth of an inch at the large end, and almost a sixteenth at the small end. I was put in a rather embarrassing situation, having already drilled and reamed all the holes taper, supposing both taps were of the same size; but the result was, when we put the taps in the holes, the Pratt & Whitney tap would go in all right, but the holes were too large for the Morris & Tasker tap. The result was, I could not proceed with the work. I went to several dealers in Cleveland, but could not find any taps to suit either of the two taps I had. After examining about twenty taps, I found no two of same size even of the same make. My experience was the same as Mr. LeVan's with the nuts he bought to fit

bolts made by same party. Now, it does seem to me very important that some established size and taper should be given to all fittings and taps, even if the fittings do vary in their widths and proportions. I consider the proportions of a fitting secondary to a standard diameter and taper for the thread.

Mr. Henning.—I had exactly the same trouble in using fittings. I compared four different taps and dies, and I found they were all different, and so different that neither one of the taps would fit the thread cut by the other. I tried them all round, every way. The only way to make a good fit was to cut a tap in a lathe to match the die that I had of a certain maker. Neither one would fit any of the others.

Mr. Baldwin.—Mr. President, is not that an argument for standard fittings?

The President.—It is not an argument for the appointment of a committee on this subject. It is all right; but the question is, How much can we accomplish by it? It is before the Society, but the point I wish to make is this—simply as an individual, not officially—whether the influence of the Society, through its transactions and the expressed opinions of its members, will not go farther, perhaps, than the appointment of a committee. If we appoint a committee to consider this subject, it will become a sort of a charnel house for all that is said on the subject; whereas, what we say now is fresh, and will be spread broadcast, perhaps, through the country so far as it is worth going; and we can personally, perhaps, influence men. Certainly I feel as strongly as Mr. Baldwin on the subject.

Mr. Baldwin.—I want to state, for the benefit of the gentleman that asked about taps, that in Robert Briggs' last paper he will find what he wants on tap and threads pertaining to fittings. It is very complete there. It is in the Proceedings of the Institute of Civil Engineers of Great Britain, 1882–83, part I.

Mr. Grant.—Mr. President, for eight or nine years I had charge of the tap and die department of the Pratt & Whitney Company, Hartford, and when we started to make pipe taps we went to a great many different people who were making pipe taps to find what the standard taper was. The standard sizes we got at very easily, and the point of the taper was turned so that it just came through the gauges; but when we came to the taper we found it varied all the way from five-eighths of an inch to an inch to the foot. We took a set of taps that was made in Philadelphia, and

we put that into a lathe with a taper-turning attachment. We found the taps from that maker varied from a half-inch to an inch and an eighth to the foot. (Laughter.) We adopted an inch to the foot. I have not anything to do with the Company now, and have not had for two or three years. I understand that they have changed that taper to three-quarters of an inch to the foot, as being the recognized standard taper.

CRANES: A STUDY OF TYPES AND DETAILS.

BY

HENRY R. TOWNE, STAMFORD, CONN.

In the study of any special class of machines it is often conducive to a better understanding of the subject clearly to enumerate the several types or forms in which the machine is used, and also to consider each of its more important details separately, rather than in their combination with other elements of the mechanism. It is proposed in the following pages thus to treat the subject of Cranes.

The only English text-books descriptive of cranes are Glynn's, which treats of English practice in crane building as it existed more than thirty years ago, and sundry catalogues published by English dealers in machinery as a means of advertising the products of the various builders of cranes for whom they act as selling agents. The practice represented in the former is now almost obsolete, by reason of the improvements which have been effected, and the latter consist of little but a series of pictures of various cranes, without descriptive text, and with no information as to the details of their construction.

The building of cranes has long been recognized in Europe as one of the most important subjects in the field of mechanical engineering, and cranes of many forms are there seen applied to an almost infinite variety of uses. In America, on the contrary, cranes are but little used or appreciated, in comparison, at least, with the extent of their application in European countries. It is the purpose of this paper to present to American readers a brief classification and description of the most important types of cranes, and a similarly brief study of the more important elements entering into their construction, the object of the latter inquiry being to determine, if possible, the best forms of elements to be adopted.

With a better knowledge of crane construction will surely come a better appreciation of their economy and value as labor-saving machines. In hundreds of mills and workshops heavy material is now being moved and handled by manual labor at an expense so much in excess of the cost of doing the same work far more rapidly

and conveniently by cranes, that the saving effected by the latter would yield an annual profit of from twenty to fifty per cent. upon their first cost, while in many cases this outlay would be entirely repaid by the economy of one year's use.

CLASSIFICATION OF CRANES.

A *hoist* is a machine for raising and lowering weights. A *crane* is a hoist with the added capacity for moving the load in a lateral or horizontal direction.

All cranes, therefore, are provided with hoisting mechanism, and, in addition, must be capable of moving the load in one or more horizontal directions. This second function is effected in some types of cranes by simply pushing the suspended load, in others by the operation of a distinct mechanism.

Cranes are most clearly classified by reference to their modes of transferring their loads horizontally; and, thus considered, are found to divide themselves into the following groups, viz.:

1. *Rotary*—In which the load is revolved around a fixed centre, such as a mast or column.

2. *Rectilinear*—In which the load is moved in straight lines, in one or more directions.

Both types of cranes are subdivided into two general classes as to their movements, viz.:

(*A.*) *Fixed*—When their supporting members are fixed in some permanent location.

(*B.*) *Movable*—When the crane as a whole can be moved about.

And into four other general classes as to their source of motive power, viz.:

(*a.*) *Hand*—When the motions, either vertical or horizontal, are effected by manual power.

(*b.*) *Power*—When the motions are effected by power derived from line shafting driven by a stationary engine or other fixed motor.

(*c.*) *Steam*—When the motive power is derived from a steam engine attached directly to the crane itself and moving with it.

(*d.*) *Hydraulic*—When the motive power consists of hydraulic pressure obtained from a pump or accumulator, and carried to the crane by pipes.

A further distinction is covered by the term locomotive, which

is applied to cranes (usually of the rotary type) which are capable of propelling themselves upon a roadway or track.

Rotary cranes comprise the following principal types, viz.:

1. *Swing Cranes*—In which the central mast is pivoted to the floor and roof of the building, and the load is suspended from a block fixed at the outer end of an arm projecting horizontally from the mast, the only horizontal motion being one of rotation.

2. *Jib Cranes*—In which the central mast is pivoted to the floor and roof of the building, and the load is suspended from a trolley traveling in and out upon an arm or jib projecting laterally from the mast.

3. *Column Cranes*—Which consist of a jib crane constructed to revolve around or upon a fixed column forming the support of a building or floor.

4. *Pillar Cranes*—In which the central column or pillar is entirely supported by a heavy foundation built at its base, and the load is suspended from a boom projecting from the pillar and revolving with it or around it.

5. *Derrick Cranes*—Which consist of a jib crane for yard use, the upper end or pivot of the mast being held in position by guy-rods or stays, instead of by attachment to a roof or ceiling.

6. *Walking Cranes*—Which consist of a pillar or jib crane mounted on wheels, and arranged to travel by power or by hand upon one or more rails.

7. *Locomotive Cranes*—Which consist of a pillar crane mounted on wheels, and provided with a steam engine and boiler, the power of which is available for operating the crane and for propelling it upon its tracks.

Rectilinear Cranes comprise the following principal types:—

1. *Bridge Cranes*—In which a fixed bridge spans an opening, and the load is suspended from a truck or trolley capable of moving across the bridge.

2. *Tram Cranes*—In which a truck or short bridge, from which the load is suspended, is arranged to travel longitudinally upon a pair of overhead rails, but is without capacity for transverse motion.

3. *Traveling Cranes*—In which a rectangular space is provided with overhead tracks upon two of its opposite sides, and is spanned by a bridge arranged to travel longitudinally upon these tracks, the load being suspended from a truck or trolley capable of moving transversely across the bridge, so that the load may be moved to or from any point within the entire rectangle.

4. *Gantries*—In which an overhead bridge is supported at each end by a frame, or trestle, extending downward, and having wheels in its base to permit of travel upon two longitudinal tracks laid upon the ground, so that the entire structure can move endwise upon the latter, and the load, which is suspended from a truck or trolley on the bridge, can be moved transversely across the bridge.

5. *Rotary Bridge Cranes*—Which combine a rotary with a rectilinear movement, and consist of a bridge having one end pivoted to a central pier or post, while the other or outer end travels on a circular overhead track, or is supported by a gantry frame traveling upon a circular track upon the ground, the load being suspended from a truck or trolley traveling transversely across the bridge.

The above nomenclature will be adhered to in the following descriptions of crane construction.

CRANE DETAILS.

HOISTING GEAR.

The most important factor in the economy and convenience of a crane is the mechanism by which the load is lifted and lowered, as it must necessarily come into action every time the crane is used.

In all applications of power, from whatever source derived, it must be remembered that the gearing of a machine can only modify the power applied in one of two ways, viz.:

(1.) By reducing its velocity, and proportionately increasing its force or "pull."

(2.) By increasing the velocity, and proportionately decreasing the intensity of the power transmitted.

Under no circumstances, unless the motive force is increased, can power be gained except by a sacrifice in speed, or can speed be increased except by a sacrifice in power. If either or both must be increased without diminishing the other, it can only be accomplished by supplying more motive power.

The function of gearing, then, is to change the force or direction of the power applied. If it is well designed and constructed, this may be done with only a small loss from friction; while, if badly made, the gearing may absorb much power in wasteful friction of its moving parts.

In machinery for hoisting, the "purchase," or conversion of

velocity into lifting power, is usually effected partly by a multiplication of the ropes or chains of the tackle through which the load is suspended, and partly by gearing within the machine, which latter thus becomes an important feature in crane work. The gearing ordinarily used for this purpose consists either of spur wheels and pinions, or of worm wheels and worms, or both combined, and the smoothness and economy of power of the machine depend largely upon the manner in which the gearing is made.

A second feature of prime importance in the hoisting gear of a crane is the mode of sustaining the load, and guarding against its "running down" when the application of the motive power is discontinued. This has heretofore been accomplished, in machines having spur gearing, by a ratchet wheel, the pawl of which has to be entirely disengaged to permit lowering to occur, or by a brake which, when on, prevents all motion of the machine, and which requires to be held or thrown off, both in hoisting and lowering. In machines having worm gearing, the end is attained by a construction of their worm wheels such that the friction between the worm and the wheel is sufficient to prevent the backward rotation of the worm under the pressure of the teeth of the worm wheel caused by the load, the resistance thus generated sufficing to prevent the running down of the load.

The worm-wheel system is usually safe against accidents, but is not economical of power if the worm gears are proportioned, as above explained, to hold the load suspended without running backward when the application of power ceases, as is usually the case. The spur-wheel system, on the other hand, is a constant and inevitable source of great danger, both to the load and to the operator. With the least carelessness in lowering, the load begins to descend with great velocity, and the mechanism is driven backward with corresponding speed and violence. If not checked, the load then practically falls as if unsupported. If too suddenly checked, violent strain is thrown upon the entire frame of the crane and on its gearing, which latter is thus liable to damage, and even to "stripping" or fracture, in which event the load falls. Where spur-geared cranes are operated by hand this "running down" of the load involves a reversing or "flying back" of the cranks, which then frequently strike the men before they can escape beyond their reach. Accidents of this kind, resulting in injury to limbs, and even to life, are constantly happening with common cranes, and are reported almost daily in the newspapers.

It is possible, however, so to proportion worm-gearing as to place it almost, if not wholly, upon a parity with spur-gearing in regard to economy of power transmitted, and, by the use of cut worm wheels, driven by turned worms or pinions (the teeth of the wheel being formed by means of a chasing hob or cutter), so to construct worm-gearing that it becomes the best and most convenient form of gearing for use in crane mechanism. It is found that gearing thus made will not automatically support the load, and that the latter, if left suspended, will drive the worm-gearing backward, but in this case the descent of the load is quite slow, and no perceptible acceleration takes place, so that the worm gears thus act as a governor to control the load. By the application of a small brake to the worm-shaft this tendency is counteracted, and, by connecting this brake with the levers which control the motions of the mechanism, the brake is easily made automatic, and thus securely holds the load whenever the crane mechanism is at rest.

In all cranes, except those of small size, provision should be made for one or more changes of speed in hoisting and lowering, so that the speed may be varied according to the load and the nature of the work to be done. Cranes operated by power *may* be so constructed that the maximum load can be lifted at the quickest speed; but they are usually so proportioned that this can be done only at a slow speed. By this plan much economy of gearing, space and cost is effected, and the practical efficiency of the crane for all ordinary uses is not impaired. The most perfect construction is one that permits a change of speeds to be made whether the hoisting gear is in motion or at rest, and which sustains the load automatically while a change of speed is being made.

The hoisting gear of a crane should therefore attain the following results, viz.:

(1) Such changes in direction and velocity of the power applied as will give the desired motions to the load.

(2) The accomplishment of this with a minimum loss of power through friction.

(3) The safety, both of the operator and the load, under all conditions; to insure which the load must be always self-sustained and incapable of "running down."

(4) Capacity for changes of speed and for convenient transition from one of these to another at will, whether the gearing is in motion or at rest, and for the automatic support of the load during the act of changing speeds.

TRAVERSE GEAR.

In this, as in the hoisting gear, good design and construction are essential to economy of power, and frequently to safety against accidents.

In some types of rotary cranes no traverse mechanism exists, except an arrangement of parts which provides for the rotation of the crane. In others, such as jib and derrick cranes, provision must also be made for moving the truck or trolley horizontally on the jib, and the same provision is required for moving the trolley of bridge and traveling cranes transversely on the bridge. In all such cases a separate mechanism, distinct from the hoisting gear, has heretofore been employed, and is still sometimes desirable or convenient. When employed, its parts should be as few and simple as possible, and it should be so far independent of the hoisting gear as to permit either to be used at any time separately or conjointly. In power cranes provision should be made for accelerating the speed of the trolley-travel whenever the nature of the work admits of it. The best possible result is attained when travel of the trolley is effected without varying the vertical position of the load, and without causing useless movement of the hoisting chain or rope over the sheaves through which it supports the load, which movement would involve much additional friction, and cause rapid wear of the chain or rope.

In traveling cranes a point of great importance is the parallelism of the bridge travel with the longitudinal tracks. Any defect here results in increased resistance to traction, and any considerable error might cause derailment. In traveling cranes, as heretofore built, the use of flanged wheels has been relied upon to prevent derailment, and the propulsion of the bridge has been effected by a transverse shaft extending the whole length of the bridge, and connected by gearing with the truck wheels supporting each end of the bridge, so that, by revolving the shaft, the truck wheels would be rotated, and the bridge be thereby propelled, provided the adhesion between the wheels and the rails was sufficient. In some instances, where the adhesion has not been sufficient to prevent slipping, a cast-iron rack has been laid adjacent to the longitudinal tracks, and extending their whole length, and pinions, gearing into this rack, attached to the axles of the truck wheels, so that propulsion is effected independently of the adhesion of the truck wheels to the track. If the load were always central on the bridge, and

the motive power always applied to this shaft at the centre of its length, this plan would answer well, although it is somewhat clumsy; but in practice the load is constantly varying in position, and the motive power is applied at one end of the long transverse shaft, so that torsion of the shaft induces a considerable variation in the travel of the opposite ends of the bridge. This error is a constantly varying one, according to the portion of the load resting upon each truck, as determined by the position of the trolley, the load being never equally distributed between the two trucks except when it is exactly in the centre. It follows, therefore, that this system of bridge travel, although operative, is radically defective, and that its use involves a constant loss of power by needless friction, and entails a proportionate amount of wear and tear of rails, wheels, and driving gear.

A better and more simple method of bridge propulsion has lately been introduced, by means of which the longitudinal motions of the bridge are effected by *pulling* each of its ends, simultaneously and at equal speed, in the desired direction. For this purpose light wire cables are used which, by a very simple and ingenious arrangement of guide-sheaves, are made to act as a "squaring device" to hold the bridge at all times perpendicular, or square, to the tracks upon which it travels. By this system the friction of traction is reduced to a minimum, and the danger of derailment from unequal travel of the opposite ends of the bridge entirely obviated.

From the above facts it becomes evident that a perfect system of bridge propulsion must hold the bridge always absolutely square with its tracks, and must propel the opposite ends of the bridge in the same direction, at the same time, and at the same speed, however unequally the load may be distributed. It is desirable also that, in large cranes at least, provision be made for starting the bridge slowly from a state of rest, and then increasing the speed, and also for varying the speed while the bridge is in motion.

CHAINS *versus* ROPES, AND CHAIN WHEELS *versus* DRUMS.

In almost every type of crane the load is primarily carried upon a flexible cord of some kind. This usually consists of rope, either hemp or wire, or of chain. Each of these has distinctive merits and objections.

Ropes have the advantage of being formed of many parts or fibers, so that no splicing or welding is necessary in their manufacture; and they thus have an assured and practically uniform strength throughout their length.

Chains, on the contrary, consist of a series of independent links, each of which is formed from a straight bar, and welded, so that a single imperfect weld injures the whole, the strength of a chain being obviously limited by the strength of its weakest link. By care and good workmanship, however, this danger can be avoided, in which case the chain becomes as safe as the rope, and much more durable.

Where a rope is used, the hoisting gear must necessarily include a drum or barrel upon which the rope is wound up when hoisting takes place. Chain may also be thus wound up on a barrel, and this has heretofore been the common practice when chains have been employed in crane construction, and a prominent feature in cranes of large capacity has usually been a proportionately large "winding barrel" to receive the chain. A chain, however, admits of another mode of construction, which consists in substituting for the wide barrel or drum a pocketed "chain wheel," consisting of a narrow wheel or sheave, of a width only slightly greater than that of the chain, and having formed upon its periphery a series of indentations, or "pockets," exactly corresponding in size and shape with the links of the chain, so that the chain and the pockets fit together accurately, and slipping of the chain upon the chain wheel becomes impossible. It thus follows that rotation of the chain wheel causes positive motion of the chain at a speed equal to the circumferential velocity of the wheel, in a manner precisely similar to the motion of a rack driven by a pinion, or of one spur wheel driven by another.

To be used in this way, it is necessary that the chain should have a constant and uniform "pitch," that is, that every link should be exactly alike, so that the distance from link to link shall be always the same (just as in spur gearing the spacing, or pitch, of the teeth must be uniform), and also that the pitch or spacing of the pockets of the chain wheel corresponds accurately with the pitch of the chain. If this be done, and if the chain have a cross section of such area that, when carrying the full load, it is not strained to its elastic limit, or to a degree which will cause any permanent elongation of its links, then a chain may be thus used, in engagement with a pocketed chain wheel, as well and as safely as on a barrel. Indeed, a properly shaped wheel of this kind is much easier on the

chain than a winding barrel or drum, for the reason that the latter has a cylindrical surface, while the bearing face of the former is not cylindrical but polygonal, the bed or bottom of each pocket being tangential to the radius at its centre, and so presenting a flat surface for the parallel sides of each alternate link to bear upon. When the chain is wrapped upon a cylindrical barrel, on the other hand, the straight sides of every alternate link, being tangential to the surface of the barrel, can each touch it at one point only, the link being unsupported throughout the rest of its length, and the tendency of the strain induced by the load is to bend each of these links to the contour of the barrel. This effect may be easily seen in any chain which has been wrapped, under severe strain, upon a cylindrical barrel, unless the diameter of the barrel be very large. The spiral grooving of a barrel does not remedy this fault, although it affords a much better bearing for the chain than a plain cylinder; which latter is only permissible for small chains and light loads.

For heavy cranes hemp ropes are rarely used owing to the size and multiplicity of parts required, and to their rapid wear. They are also inadmissible where liable to be exposed to much heat as, for instance, in a foundry. Wire ropes are more available, and are often employed, but these also wear rapidly, unless the sheaves and barrels around which they pass are of large diameter, while this requirement, if met, reduces the effective height of hoist and necessitates more parts or gearing to obtain the necessary purchase, and augments the bulkiness of the machine. Either material involves resort to a large winding barrel or drum.

The usual and best device for large cranes is well made chain, and this, when used with pocketed chain wheels and sheaves, gives the best and most satisfactory results, and leaves nothing to be desired. The adoption of this plan dispenses with winding barrels, preserves the shape, and therefore the durability, of the links of the chain, and in every way simplifies and compacts the mechanism.

The relative merits of the several systems may now be summed up as follows:

(1) *As to the Sustaining Cord.*

emp Ropes.—Admissible only for small cranes not in frequent use and not exposed to the weather or to heat.

Wire Ropes.—Available under any ordinary conditions, but

involving a winding barrel of large diameter and large sheaves; not economical of space.

Chains.—Possessing, if well made, all advantages and the greatest durability: *common chain*, requiring a winding drum, but permitting it and the sheaves to be of smaller diameter than with wire rope; *pitch chain*, dispensing with a drum and admitting of the use of a narrow chain wheel.

(2) *As to the Winding Device for Hauling in and Paying Out the Rope or Chain.*

Winding Drums or Barrels.—These must have a diameter and length such as will enable them to receive the whole length of rope or chain to be hauled in by winding it upon their surface in one coil, without overlapping. In large cranes the load is usually carried upon four, six, or even eight parts of rope or chain, so that the length to be wound up amounts to four, six, or eight times the effective hoist, and the dimensions of the barrel thus become very large. Moreover, this barrel must either be caused to travel longitudinally on its shaft, so that the rope or chain as it leads off shall be always in the centre of the crane and hoisting mechanism (which method of construction involves serious complication and greatly widens the space occupied by the gearing), or the rope or chain, as it uncoils, be permitted to vary in position from one end to the other of the barrel, in which case it is nearly always out of centre, thus inducing objectionable lateral strains and causing greater friction and wear.

Chain Wheels, with Pockets.—These require a width only slightly greater than a single part of the chain, and a diameter merely sufficient to give the proper engagement with it, so that both dimensions become much smaller than in a winding barrel, and the total space occupied is but a small fraction of that required for the latter device. The *chain wheel* is fixed in direct line with the chain, and all lateral strains are avoided, while the flat bearings afforded for the chain by the pockets preserve the shape of the links and protect them from bending strains. The slack chain, after passing over the wheel, falls into a proper receptacle below.

From this analysis of the facts is deduced the proposition that chains, if well made, constitute the best form of flexible cord for sustaining the load in a crane, and that a well constructed *chain wheel* (as contradistinguished from a winding barrel) is the best

form of device for hauling in and paying out the chain; and, therefore, that the best method of crane construction involves the use of these two elements.

TROLLEYS AND TRUCKS.

The trolley of a crane is the movable carriage from which the load is immediately suspended and by which longitudinal motion of the load upon the jib, or the bridge of a crane, is effected. The term truck is usually restricted to the wheeled carriage used to support each end of the bridge of a traveling crane, or the corresponding part of rectilinear cranes of all kinds. Rectilinear cranes require usually at least one trolley, and one or more trucks. Rotary cranes require usually a trolley only.

The whole load of a crane is hung primarily upon the trolley, and where trucks are used, is transferred in full to them, together with the weight of the crane itself. It is desirable, therefore, that these parts should not only possess ample strength to resist the strains they may be subjected to, but also that they be so arranged that any yielding or breakage of their parts will not allow the load to fall to the ground, but only permit it to descend until the supporting beam rests on the rails upon which the trolley or truck is to travel. For this reason the construction should be such that the ends of the bridge, in traveling and similar cranes, overlap the longitudinal tracks, and the axles or housings of the trolley, in cranes of all kinds, overlap the rails upon which it runs. It is further desirable that the vertical distance between these overlapping parts and the rails be as small as possible, so that, in the event of any break occurring, the distance through which these parts pass before being arrested is so small that no serious shock can ensue. With careful designing this distance can be reduced to merely the necessary clearance of the parts, which need not exceed more than one inch or less.

A natural preference exists for wrought iron rather than cast-iron as the material from which to construct the moving parts of a crane; and, unquestionably, it is always best to use wrought iron for parts that are to be exposed to tension under heavy loads. Cast-iron, however, is the better material for those parts that are subject to compression, and by skillful designing it is usually possible so to arrange the parts of trolleys and trucks as to use cast-iron wherever stiffness or resistance to compression is required, while still employing wrought iron for the parts under tension. In this way the

greatest economy is attained, and not unfrequently a better result secured than by the use of either material alone.

The wheels both of trolleys and trucks should be true cylindrically, should be double-flanged, and, by preference, should have chilled treads. If wheels of small diameter are used, in order to economize height, they should be provided with anti-friction bushings, to counteract the increased resistance to traction caused by their small diameter. The wheel-base, or distance from centre to centre of the adjacent wheels, should be as large as possible, in order to avoid cramping between the rails, and to facilitate the easy motion of the carriage upon its track. In large traveling cranes it is desirable that the axles of the truck wheels be supported in spherical bearings, so that the wheels may adjust themselves to any yielding of the track which may result from the passage of heavy loads, and thus all unnecessary straining of the parts of the truck be avoided.

FRAMES AND GIRDERS.

In the early building of cranes, timber was chiefly used in the construction of their frame-work, and is still much employed in this country. Improvements in the manufacture of structural irons, and the large variety of shapes now obtainable, have, however, greatly altered the relative cost of construction in timber and iron, and made it possible to employ iron much more largely than formerly.

Experience in the practical designing and building of cranes of many types has convinced the writer that, by the proper use of materials, crane construction in iron costs, in most cases, little, if any more than in wood. For example: The frame of an ordinary jib crane consists of three principal members—the mast, the jib, and the brace. If of iron, each of these consists of a single piece or bar, or, in larger cranes, of two parallel pieces, and the union of these several members at their intersections is accomplished simply and very economically. If timber be used, on the other hand, more or less trussing is required, except for small cranes; and many bolts, washers and castings are necessary to provide for the proper bearing of one part upon the other and to securely fasten the several parts together. The iron frame, when once properly put together, is practically imperishable. If properly painted it will not deteriorate, nor is it affected by exposure to the weather or by extremes of heat and cold. A timber frame, on the contrary, is liable to

decay, which is hastened by exposure to the weather, and it is unfavorably affected by heat. More or less shrinkage of the timber always occurs, thereby relaxing the engagement of the several parts, and disturbing the relations of the bearings which receive the strains caused by the load. The result of these changes in a timber frame is to permit more or less working of the parts one upon the other. This tends to augment the trouble from which it arises, and as a result the safety of the crane is lessened and its durability continually impaired.

So also in the bridges of traveling cranes. If the span be great, construction in timber involves much splicing, and this in turn necessitates unnecessary material in many places. The trussing and bolting requires a considerable amount of iron-work, and usually necessitates a deeper girder than is required in iron, thus lessening the available head-room beneath the crane. It is believed that an accurate comparison of the relative costs of crane frames or girders built in wood and in iron, if proportioned with an equal factor of safety throughout, would show little if any economy of first cost in favor of wood.

The availability of iron for structures of this kind has been greatly increased by the ability of the mills to produce extreme lengths when required. No difficulty is now experienced in this country in obtaining the heaviest channel and I-beams in lengths of 50 feet or more, and the largest angle irons are also obtainable in single lengths of 80 or 90 feet. It thus becomes possible to form each of the principal members of cranes of a single continuous iron, the advantages of which are too obvious to need description.

It will be conceded that iron frames and girders are much to be preferred for every reason, with the single exception of possible economy of first cost. Taking into account, however, all of the conditions and considerations above mentioned, it is believed that the difference in first cost is so slight—in many cases not appreciable—that the frames and girders of cranes of all, except perhaps the smaller kinds, should now be built entirely of iron.

In conclusion, it may be hoped that the foregoing analysis will conduce to a clearer understanding of cranes, both as regards their various forms or types, and the more important details of their construction. The tendency of the day in all directions is toward the specializing of products; that is, the concentration of the abilities and resources of individual establishments upon the develop-

ment of certain distinct or special products. Consumers are the ones most benefited by this condition of things, since it enables them to procure products of higher quality and ultimately at a lessened cost. Where such specialists exist, the best result is usually attained by submitting to them a clear statement of the work to be done and of the surrounding conditions, and by accepting the advice thus obtained as to the type or form of machine best adapted to meet the special requirements of the case.

DISCUSSION.

Thos. R. Morgan, Sr.—The discussion in this admirable paper on "Cranes" is so extensive, that I can hardly in so short a time, discuss the specialty of traveling cranes, as they are the most important and the most complex of all cranes. It would take more time and space than I have at my disposal to do the subject justice, and to get at the best facts. The paper only came into my hands last night, and I must say has been well gotten up, with great care and has a great many facts and experiences, on one side of the question. All questions, especially of this character, however, have more than one side, and what we all need is to get at the best if possible. I desire to call your attention to some experiences and practice which I have had with cranes. The investigations I have made have been of as exhaustive a character, I think, as it has been possible for me to make, both in literature and practice, as I have made the question a study, with a desire to get at the best possible results. There are a few points of importance where I differ somewhat with Mr. Towne, which I would like to call your attention to:

(I.) *On the subject of spur and worm gearing, and with regard to the danger of using one over the other.* With the comparative practice of worm and cog gearing, I have had considerable experience, both on heavy and light work, and I must say that my experience with worm and tangent wheel gearing, has been of a very unfavorable character. I have never believed that worm and tangent wheels are a good gearing for anything that has heavy work to do. For continuous motion of a feed character or light work, I have found the worm gear best. But, for heavy, hard work, subject to the control of common labor, and to dusty conditions, to all of which cranes are exposed, I would consider them the reverse of best. My experience of the practical working fully agrees with

the theory of the operations of the teeth of worm and tangent wheels. But both theory and experience are very much against them as a reliable power, unless the teeth are fully protected from contact with each other by a closed box filled with good lubricant. Should the lubricant fail, it must be evident that if the teeth of the worm and wheel come in contact, they would soon grind each other to powder. The top or outer periphery of the tooth travels much faster than the inner periphery, or bottom of tooth of the worm, and the teeth of the tangent wheel, which is operated by the worm, run *vice versa* to the teeth of worm. In other words, the outer periphery of the teeth of the tangent wheel would travel the fastest, on the point, in contact with that part of the tooth of the worm which travels slowest. At the bottom part of teeth of tangent wheel, where its teeth travel slowest, the worm tooth travels fastest, so that it must be evident that continuously varying speeds of revolution are going on from top to bottom of the teeth of the worm, operating against the varying speeds of circumferential travel of the teeth of tangent wheel, so opposed to the natural conditions as to cause a grinding instead of a rolling motion. Another source of great trouble with the worm and tangent wheels, even with best frictionless precautions, is the face friction on end of worm, in its thrusts. This has been a cause of great annoyance under hard work. Practical men of long experience know this to be the fact, but with the ordinary straight cog gearing well made, all such conditions specified about the worm and tangent wheel are avoided, and a natural rolling of the teeth of the wheels on each other without any lubricant is the result. Such wheels under fair conditions and good designs, will last a life-time even in foundries, and rolling mills, where dust is continually flying around. Hence I contend that for "traveling crane" purposes, for simple, permanent conditions, and economy of power consumed, plain cog gear wheels are best adapted for the purpose.

(II.) *Parallelism.*—I have had experience with traveling cranes for some thirty-two years; worked with them practically, and built some of them; and practice is a very good field to get facts from. About twenty-five years ago a crane was built at the Blaenavon Iron Works, Wales, to place over the roll-turning shop. I was there at the time. It had a rack gearing alongside of the track to control the "parallelism" of longitudinal travel of bridge, which was found not to be necessary. We find to-day the best makers in

the world have done away with the rack, and depend on the traction of truck wheels alone. With regard to the danger to the parallelism of traveling cranes, when operated through a line of shafting across, I don't think that there is any. I have never known any to exist. There may be such a case through poor construction and work. I have never heard or seen the report of a traveling crane falling down in my life, and the practice of leading makers of long and large experience refutes that idea. With regard to the two flanges on track wheels, I think that the double flanges are simply made as a safeguard, so that if there *should* anything happen, the crane would wedge itself, and could not fall down. Then there are other methods of protection, if they were necessary, such as placing horizontal guide wheels alongside of the track, so that there could be no possibility of danger on that point. But the practice of many leading makers in Europe, for long periods, prove that even to be unnecessary.

(III.) *The square shaft as a motive power, versus the wire rope.*— I contend that the motive power through a square shaft along the shop, where made properly, is simple and permanent in character, and is far less objectionable than the driving through wire rope at high speed, and with the intervention of worm wheels to obtain power. The worm becomes generally necessary to reduce the speed and gain power. With such conditions as are imposed by the high-speeded wire rope, worms, sheaves and ropes have to be renewed at intervals; sheaves must be kept in order, and wear and tear of worms and small gears must be proportionately great. The life of working details is not of as long duration as it might be. Another great objection to the wire rope is the sagging of rope, whenever the lifting of loads takes place. The rope is kept in tension by balance weights, which forms another objectionable feature in work-shops. As a manufacturer of cranes, I have made the most careful investigations into the best modern practice, and taken the views of many men who have had large modern experience and long practice in that field, and for the benefit of the members I beg leave to lay before you my experience and practice resultant therefrom. At our works we have to handle a large amount of difficult and heavy pieces of machinery, and our labor force was becoming burdensome, slow, and destructive in many ways. Being driven with other work, we could not make our own crane, and we decided to order a traveling crane, of twenty tons capacity, from Appleby Bros. of London, who, no doubt, have had more experience in that

line than any other makers. We stated fully to them that we wanted their best modern traveling crane. They advised that our crane be driven by a square shaft, supported by tumbler bearings, as the best. The shaft we were to make ourselves. It was to be made in a number of ordinary lengths, spliced, and riveted in the best manner. In their experience they had found it best not to advise that these shafts should be more than three hundred feet long on that system of driving to do such work. Soon after receiving their drawing, one of the most experienced engineers of England, and now one of its leading builders of machinery, paid us a visit. He is also a large manufacturer of cranes. I asked him why the Applebys did not advise a shaft longer than three hundred feet. He said they gave way at the joints. This confirmed my views, and led me to determine to make the main shaft of our crane one hundred feet long, in one piece of three-inch square iron. This has been in operation for about one year, and I am convinced that it will stand the hard work of a life-time, without any renewal, as far as the shaft itself is concerned.

TRAVELING CRANES IN GENERAL.

In our Appleby crane there are a number of excellent practical features. Important prime features will bear great improvements, and, I am sorry to say, the workmanship throughout bears no comparison with our practice in this country, and has been a source of great disappointment to us. But in its practical operations of doing the work, barring the terrible noise the crane makes, owing to minor defects and bad work, I considered our crane, three months ago, the best practical working crane of its kind that I have yet seen in all my investigations, of many and most modern of various makers' cranes. After carefully watching our own crane in operation I prepared a new design to improve all defective parts, simplifying and quickening the many changes, and at the same time aiming to make a crane as nearly noiseless as possible, as well as to place the crane under the control of a common laborer, or boy, who can read a few simple words placed over each handle, operating the changes of motion, such as "Quick," "Slow," "Up," "Down," "In" "Out," Brake. The latter is controlled by the foot, and the load in lowering is always, if desired, controlled by the foot. The traveling motions, both longitudinal and crosswise of bridge and carriage, are controlled independently of the operator. Stop or disen-

gaging motions are placed at each end of the travel. All these conditions, we have been enabled fully to carry out with detailed success, to our full satisfaction and to that of our customers, and some of the leading and most experienced manufacturers of locomotive and stationary engines. The Dickson Manufacturing Company, Scranton, Pa., have a crane of fifty feet span, and of twenty-five ton capacity. The shaft is two hundred feet long in one piece. We have been signally aided in our efforts to improve a most important defect in the Appleby crane by substituting the Frisbie patent friction clutch, which enables us instantly to stop and to start every operation of the crane, and at the same time to reduce the speed of first driving shaft by one-third. This results in reducing wear, and in making the crane practically noiseless, giving immediate instead of slow changes. We have a number more of larger capacity of same kind now building. We cordially invite members interested in this subject to call and see the Appleby crane, and we have no doubt that the Dickson Manufacturing Company will welcome any member to see theirs. Examine, also, into the practice of others of modern make and different type. Judge and reason for yourselves as between the two systems, as shown in their practice. This is the way we did in selecting our present system, to which we are only tied where we believe it best. We believe that any member who will carefully examine in detail the cranes on this system, as strengthened and improved, with ample power of simple cog gearing controlled by stop motions, and calculating Frisbie's frictional adjustments, will find, instead of danger anywhere, that the controlling features throughout are simple, permanent and economical. As to the improved traveling crane as now built, it is embarrassing for a member who is a manufacturer to discuss questions in his line of business. But as I consider that the Society of Mechanical Engineers desire practical facts, and that it should be supposed that a manufacturer in a line of business should have experience and knowledge in that line, and is desired in discussion to give his experience and views freely, I have done so, in this spirit only, leaving my practice to the investigation of the members, for them to ascertain whether they will bear me out or not.

Mr. Walker.—In Mr. Towne's paper of this morning, I notice some remarks comparing the regular round drum to a pocketed chain wheel. I had better read, perhaps, a few lines that will preface what I want to say:

"Indeed, a properly shaped wheel of this kind is much easier on the chain than a winding barrel or drum, for the reason that the latter has a cylindrical surface, while the bearing face of the former is not cylindrical, but polygonal; the bed or bottom of each pocket being tangential to the radius at its centre, and so presenting a flat surface for the parallel sides of each alternate link to bear upon. When the chain is wrapped upon a cylindrical barrel, on the other hand, the straight sides of every alternate link, being tangential to the surface of the barrel, can each touch it at one point only, the link being unsupported throughout the rest of its length, and the tendency of the strain induced by the load is to bend each of these links to the contour of the barrel."

This is the point I want to explain. The pocketed chain wheel described is very popular; and justly so. It saves the chain from being damaged in the links, but it cannot be applied advantageously on drums. The fact brought out in Mr. Towne's paper is that links will be destroyed or broken by lying flatwise on the barrel. The point I want to bring out is that flat links should not bear on the drum. The vertical link working in the groove should touch on the bottom of groove only; a chain passing over a wheel or drum should pass over with the alternate links at right angles, the horizontal links never touching the barrel. I think this is worthy of notice, and will meet the objection made in Mr. Towne's paper to the destruction of chains on cylindrical drums or wheels. Some time ago our Government of this country investigated this very question as to chains running around cylindrical drums. I understand, after investigation, it was found that their chains were breaking from the ill-effect produced by the flat link bearing on the drums. Afterward the drums were made so that the vertical links would always bear on the bottom of the grooves.

Mr. Collins.—I have made a little sketch on the blackboard, showing a method by which two drums can be used to avoid winding the chain on a spiral drum. The grooves for the chain are made so that the groove on one drum comes opposite the high place on the other drum. The chain from this groove passes over on that one and back on this groove, and has the effect of a spiral drum, and yet the chain can always be in the same place, the chain always coming on one drum in the same groove, and always passing off the other drum at same place. There is one objection—that the binding force of the chain around the two drums

has a destructive effect upon the bearings; but to obviate that, place upon the drum shafts friction wheels the same diameter as the drums, and upon the driving shaft, which is between the drums, put a roller bearing on these wheels, and you have the whole thing. This kind of a drum will work, and work well, and it never changes the position of the chain. It has all the advantages of a spiral drum without its disadvantages.

Mr. Oberlin Smith.—Mr. President and Gentlemen: There was a point touched on by Mr. Morgan this morning, among other things, that I think of a great deal of importance, and that was what we may call "hoisting nomenclature." It is the custom in a great many places where hoisting machinery is used to give the word of command in such terms as "Hoist her down," "Now, let her go," "Let her run a little," "There, now, that will do," "Run her out a little," "Run her back," "Whoa! there," and all such terms, sometimes in a very indistinct voice. This is, undoubtedly, a source of danger, especially with power cranes, which move quickly, and there should be provided near every hoisting machine a card stating what words of command are to be given, in all cases where words can be heard at all. There are cases where there is so much noise that a code of visual signals should be adopted, but in most cases words can be heard if they are properly spoken; and, of course, they should be sharp and crisp, perfectly plain and definite, and the same word should always mean the same thing. I know in one of the best shops in Philadelphia some years ago the practice was to say anything at all. A very frequent expression was, "Hyst her away now." My practice is to have a code of words which must be strictly adhered to—simply "Up," "Down," "In," "Out," "East," "West" ("North," "South," if the crane happens to so stand), and "Stop." Just these seven words will manage an ordinary crane. Of course, where there are more motions other words are necessary, but they can all be just as short as these; and if the workmen are allowed to use no others, and are trained in speaking distinctly and loudly, it may in some cases save serious accidents.

Mr. Capen.—I should like to say, in connection with the subject just referred to by the gentleman, that it has been the practice in instructing the operators of cranes manufactured by the Yale & Towne Manufacturing Company, to take their directions from motions of the foreman or whoever may have charge of the job. There are no words used whatever. He makes his motions, up or down,

as the case may be, with the hand, and a quick upward motion of the hands stops all motions. I find that to work much better than any shouting.

In regard to the discussion, I am very sorry that Mr. Towne is not here to take his side of the question. I hardly feel capable of it. I hope that you will give him an opportunity to reply in the minutes. I should like also to say that in preparing his paper he was very careful indeed to avoid all business discussions. I know he devoted a good deal of pains to writing a treatise as well as possible without bringing the matter of business into it.

The President.—I believe it is a rule of the Society that members have the privilege of so correcting the stenographic report that they can say what they intended to say instead of what the reporters sometimes make out they said. A great many men can think better sitting in a chair with a pen in their hand than they can on their feet. So that I think the rule of the Society has been for them to write out their remarks made in discussion. Is there any further discussion?

Mr. Morgan.—Mr. President: I would like to say one word. I think that in societies of this character a great deal of liberality should be allowed, and, I believe, is generally allowed; that when any person shall speak on a subject pertaining to something that he is manufacturing, or in which he has an interest, it should not be understood that the person, when talking before the mechanical engineers is talking for self in the matter, but it should be understood always that those who manufacture or have an interest in something are supposed to know more about it, and to have given more attention to that subject, and anything that they say should be always considered, I think; and while they have to bring self in, it is a very embarrassing thing; and that was my trouble this morning. I felt very much embarrassed. I came here for education, and to do all I could to extend any knowledge that I have, with the sole purpose of calling attention to facts, and I hope that it will be always be understood so; and I think, as I said at the start, that members should be supposed and expected to know more about subjects that they are devoting their lives to. And I believe Mr. Capen understands that while I am fervent in anything I may say—we have different methods of expressing ourselves; and while I do that honestly, with the intention simply of education alone, I hope it will be considered in that way; and I am very much pleased to know that I can give my views in a corrected form. [Applause.]

Mr. Durfee.—Mr. President: I am not a manufacturer of cranes, but nevertheless I have occasionally ventured to build a crane or two. I have put on the blackboard here a rough sketch of a traveling crane that I built over ten years ago for lifting the "rolls" from a "rail" and "top and bottom train." It is made of two timbers running lengthwise over the train of rolls; these are supported at the end by two posts which are properly braced on a sill. This sill is supported by wheels which run upon a track on the floor. The other end of these timbers are supported upon an overhead truck. Stiffness to the structure is also given by this brace. It is a hand crane, the infrequency of its use making it undesirable to apply power to it. The lifting chain fastens to a block here [indicating], goes over a pulley, and comes down here. This crane is applicable to hardly any other kind of work except the kind for which it was designed. It is now at work, answers its purpose very well, and is of very cheap construction.

(Mr. Durfee illustrated on the blackboard the construction of his crane.)

Another crane of different construction which I made some years before—in 1863—has a traversing carriage running upon two cast-iron girders supported upon posts. This carriage has on it a hoisting drum, actuated by a worm wheel and worm. This worm slides upon a shaft, there being a slot in the shaft and a feather in the worm. The worm takes an end bearing against brass collars that rest against some rubber springs, so that when the weight is lifted it has an elastic resistance, the worm being allowed to slide lengthwise on the shaft until the springs are compressed sufficiently to hold the weight, and thus the weight is lifted without a jerk.

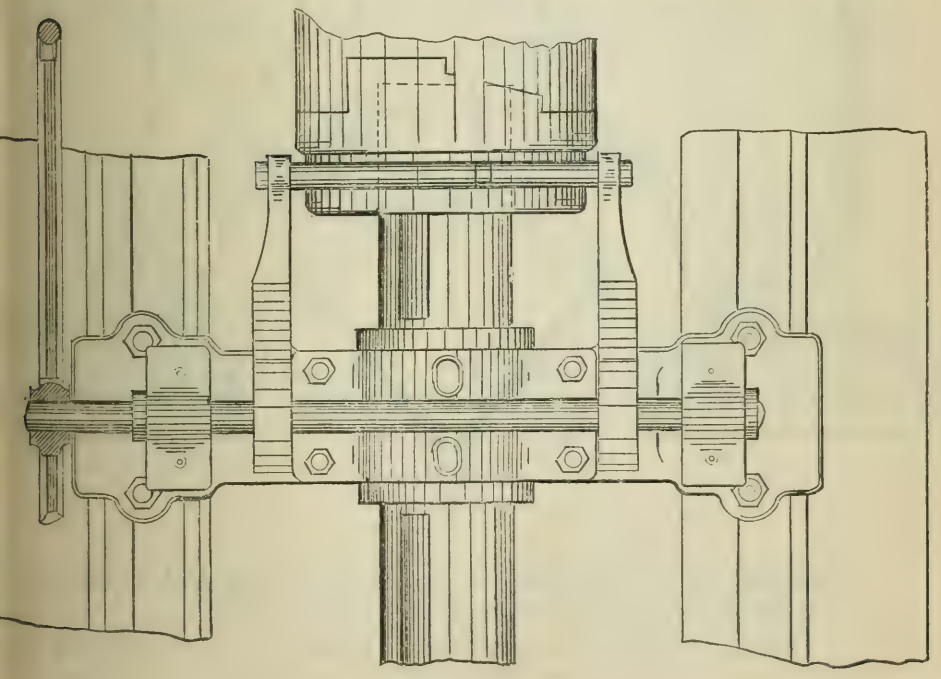
In conclusion, I will say that this traveling carriage and the suspended weight were pulled lengthwise the girders by precisely the arrangement mentioned in Mr. Towne's paper. There was a shaft at each end of the girders and two chains, which insured a parallel movement to the truck.

MECHANISM FOR MANŒUVERING CLUTCH COUPLINGS.

BY

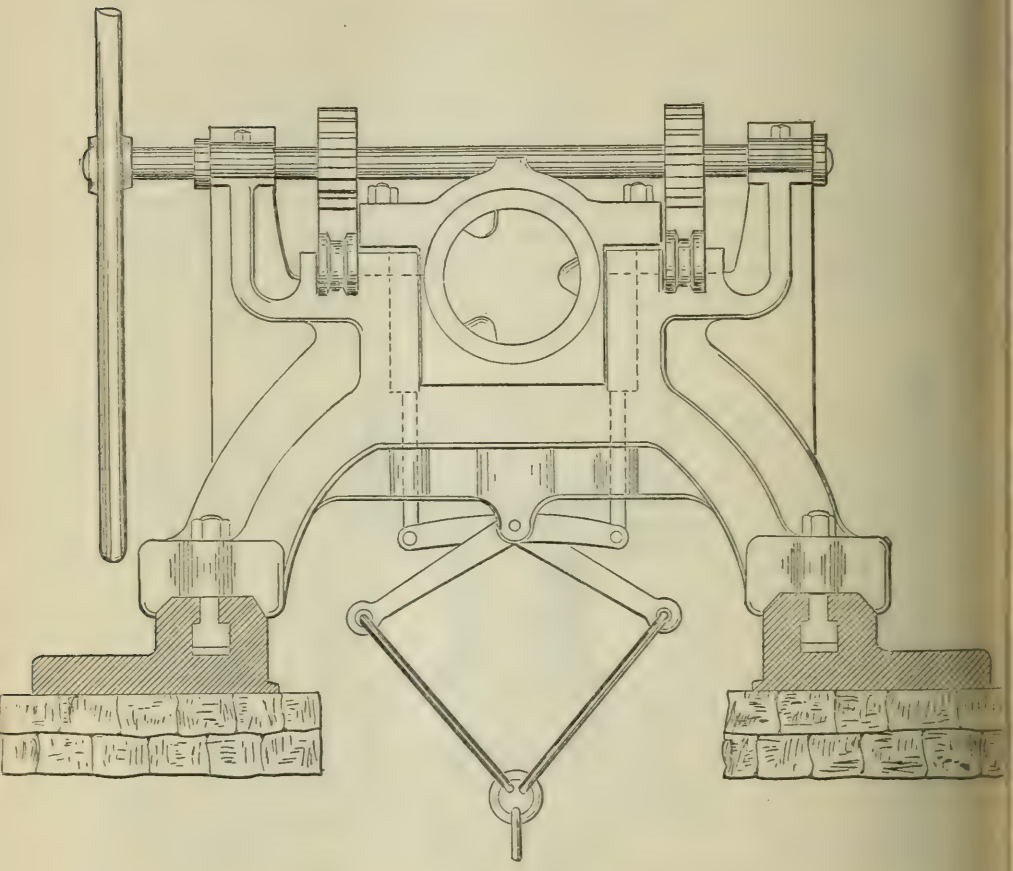
W. F. DURFEE, BRIDGEPORT, CONN.

The method of manœuvering clutch couplings by means of a lever the extremities of whose forked shorter arm act within a groove surrounding the movable part of the coupling, has been a common mechanical expedient for centuries. Branca, in his work on Machines, published in Rome, 1629, gives two illustrations of its use, and for clutches of moderate size, transmitting but small amounts of power, this old and well-known device is in every way satisfactory. But when the clutch to be shifted is of large size and



great weight, as is the fact in many instances in modern establishments for the manufacture of metals, the great length and cumbrous character of the lever required, and the fact that it is

almost sure to occupy valuable space, constitute it, in many instances, a sort of negative nuisance—an uncouth and disagreeable necessity. For the purpose of avoiding the various objectionable inconveniences attending the employment of the lever for shifting large clutches, the writer many years since designed the mechanism

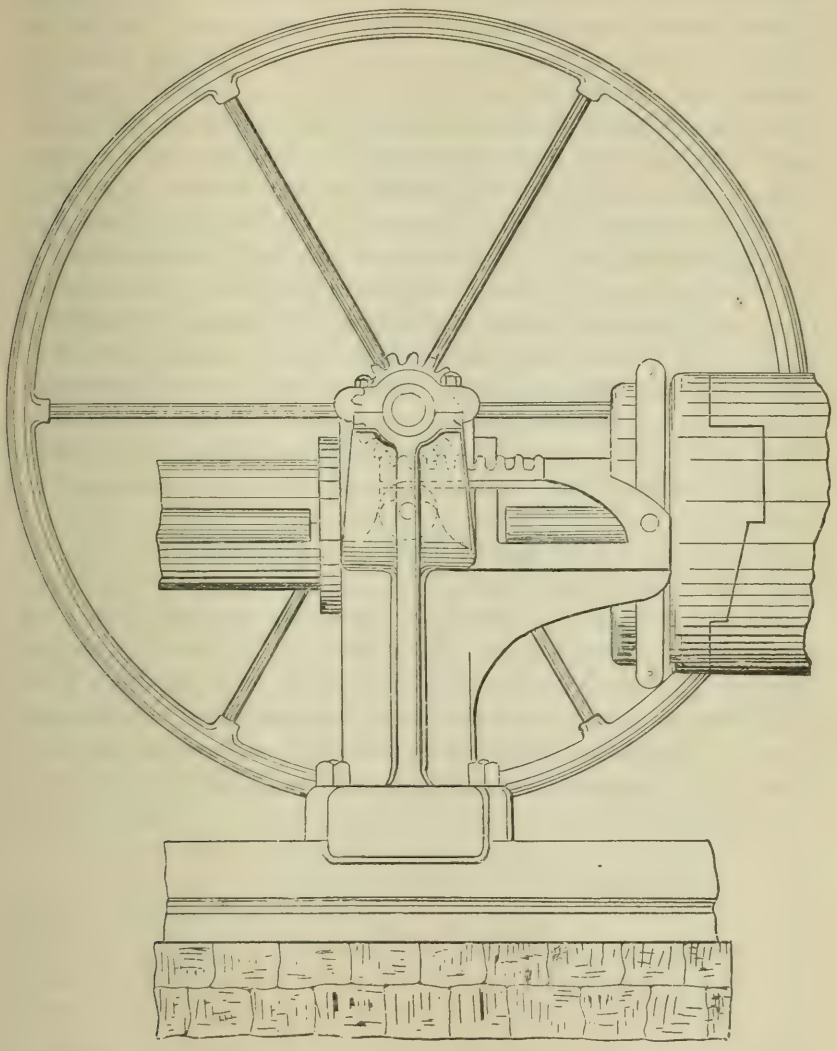


illustrated by the accompanying drawings, and from time to time, as occasion required, has employed it in his practice.

The drawings show the apparatus as designed for manœuvering the clutch coupling transmitting power to a "rail train."

The groove in the movable part of the coupling is occupied by a hoop of wrought iron, having trunnions on its outside at the extremities of its horizontal diameter; attached to these trunnions are the curved extremities of two rack bars, the lower ends of which are

terminated by plain horizontal surfaces, which slide when the racks are moved upon the similar surfaces of projecting horns attached to the stand which supports the "main spindle," on the right hand end of which the movable portion of the clutch is located; the



opposite ends of the racks are sustained by small grooved rolls which turn in bearings on the top of the stand before named. Above these rolls, with its axis in the same vertical plane that contains the axes of the rolls, is a horizontal shaft supported in bearings

in the upper ends of vertical horns cast on the stand before mentioned; on this shaft are placed two small pinions in gear with the racks already described. One extremity of this shaft is provided with a "hand wheel" six feet in diameter, the hub and rim of which are of cast and the spokes of wrought iron. It will readily be seen that by turning the hand wheel in the proper direction the clutch can easily be thrown in and out of gear. To the links suspended from the levers beneath the supporting stand is attached a weight sufficient to sustain (through the medium of the levers and the vertical pins attached to their shorter ends) the two parts of the "main spindle" bearing and the weight of the spindle itself; in fact, this weight is slightly in excess of what would be sufficient for that purpose, and it acts to keep the spindle in contact with the cap over its journal; by this arrangement the level of the centre of the "main spindle" can be easily adjusted by means of the bolts which hold the cap down, the weight acting through the lower half of the box and the spindle itself, to keep the cap in contact with its bolts. The box for the "main spindle" bearing is rather loosely fitted in the stand, and the whole combination has a manageable flexibility and adjustability which is very satisfactory in practice.

Mr. Walker.—Will Mr. Durfee please explain why he has long and short claws in his clutch?

Mr. Durfee.—The shorter claws are for the purpose of backing up the rolls, or reversing the rolls in case a "pile" gets "stuck" in them, or in case it is desirable to do it for any purpose. That is a common construction of clutch. It is not peculiar to myself. There are a great many of them in use in mills all over the country. That is, the long and short teeth are in common use.

ECONOMY IN LUBRICATION OF MACHINERY.

BY

GEORGE N. COMLY, EDGEMOOR, WILMINGTON, DEL.

In large manufacturing establishments the sum of money paid annually for lubricants is surprisingly great, and where oil is the lubricant the quantity wasted is a very large percentage of the total amount purchased.

Being convinced that such was the case, I endeavored to ascertain the actual quantity of lubricating material used in a given time on the various machines and in the various shops connected with the establishment at which I am engaged.

The result was startling, and the investigation proved that one of the most extravagant users of oil was the vertical engine used for driving the principal part of the works used for machine shop and bridge construction, etc.

The engine was nominally 60 horse-power, with 16-inch cylinder and 18-inch stroke, with an 84-inch diameter pulley, making 106 revolutions per minute, but the indicator cards were evidence of the fact that frequently 83 horse-power was produced by the engine.

Owing to the fact that the engine was overloaded, the crank-shaft bearings and crank pin gave much trouble by heating, and occasionally it was necessary to stop the engine during working hours.

The expense for lubricating oils on this engine during the month of May, 1882, was at the rate of $3\frac{53}{100}$ cents per hour of the time during which the engine was actually running. The oil used was cosmo-lubric No. 2, costing 65 cents per gallon, and the specific gravity of the oil was 26° Beaumé.

During June the oil cost $3\frac{91}{100}$ cents per hour run, and the engine was running 120 hours per week, or an average of 20 hours per day.

About the 1st of July I commenced using No. 10 lubricine-grease on the crank shaft bearings *instead* of oil, and the result was that the engine shaft bearings worked much cooler, gave no more trouble, and the cost of the lubricating material was reduced to $1\frac{15}{100}$ cents per hour run.

The crank pin at this time was still using oil, and continued so doing until October 9th, when I had a copper box attached to the stub-end of the connecting rod close to the crank pin with a $\frac{1}{2}$-inch tube connecting the box with the crank pin bearing, and No. 4 lubricine-grease packed in it. No. 10 lubricine was also applied to the guides for the crosshead, the result being that the cost of lubrication was still further reduced to $\frac{78}{100}$ of 1 cent per hour run, and the guides and pin worked much cooler than they did previously when oil was used.

A mixture of palm-grease and beeswax in proper proportions will compare favorably in efficiency with the lubricine-grease.

I have also found mixtures of beeswax and tallow or beeswax and suet to work very well as lubricants for shafting. The relative proportions must of course be made to suit circumstances.

During the past eight months the line shafting has been running *without oil*, depending exclusively on the mixtures such as already described. The shafting is all provided with ball and socket hanger boxes, and the top half of the box has two cups cast in it in which the grease is packed, each having a cast-iron cover fitting closely over it to keep out the dust. This cover is chained fast by a very light chain to prevent it from being lost or knocked down by ladders, etc.

The center oil hole, where a self oiler is usually placed, should be stopped up with a cork to keep out dust at that point, and the use of oil is not allowed on any of the shaft bearings where the grease can be applied.

By the regulations already described the cost of lubricants has been reduced $44\frac{6}{10}$ % in the cases noted above.

Means have been provided for using the grease on nearly all of the engines running at the works and on several of the heavy machines, the result being a saving of lubricant and cool running of the journals.

It is better when applying the grease to make large holes in the caps of the bearings (perhaps $1\frac{1}{4}$ or $1\frac{1}{2}$ inches diameter if allowable) and permit the grease to be packed directly on the journal surface. Where this cannot be done, a funnel-shaped cup is attached to the oil hole, in which is a copper rod, one end of which presses against the shaft while the other end passes through a spiral spring which is tightened to the required tension by a screwed cap. The cup is filled with the grease, and the rod passing through it melts the grease by the heat caused by the friction of the copper rod on the

journal, the spring being tightened sufficiently to produce the necessary friction on the end of the rod.

Plain copper boxes, however, are frequently preferable with lids to keep out dust. A piece of copper rod run through the center of the box touches the shaft, and the hole between box and shaft is made much larger than the size of the rod of copper, so that the grease can be well pushed down on to the shaft.

DISCUSSION.

Mr. Grant.—I would like to ask the gentleman whose lubricine he uses.

Mr. Comly.—The lubricine which we have used principally is sold and, I think, manufactured by R. J. Chard, No. 6 Burling Slip, New York City.

Mr. Grant.—We use it on our shafting, and it has run perfectly cool for 18 months. We have not used a drop of oil. We have one very quick running shaft (4,000 revolutions per minute), and it runs perfectly cool; we have not used a drop of oil on this shaft.

Mr. Comly.—This engine, as I said, was giving constant trouble, and it seemed as if it was overloaded. Sure enough, it proved that by our indicator cards; and we were agitating the subject of putting in a heavier engine right away, when I finally struck on this mode of lubrication and instead of the main bearing running hot all the time and keeping water on it, we removed all supplies of water, and it runs perfectly cool now, so that you can scarcely feel any heat there at all. The metal was brass originally, and ran hot; and in heating, of course, the tendency was to inclose on the shaft. The box was made in two halves, divided on a horizontal line, and of course, after being heated and enclosed on the shaft, it had to be loosened by scraping, and that was done several times, but it still ran hot. Then there was anti-friction metal put in the box composed of lead and antimony, which we found to be a very excellent anti-friction metal. But it still heated. Then we used very heavy bodies of cylinder oil—the heaviest oil we could get—and it still ran hot. But when we put the lubricine in, it seemed to remove all difficulty.

Mr. Grant.—I would like to ask the gentleman what the small springs are.

Mr. Comly.—The small spring is on a little copper rod which Mr. Chard furnishes with his cups. The end of the rod passes through a little cap, and the spring presses against the under side

of the cap. That cap is adjustable on the top of the cup, by means of a screw. The cap is to be screwed down just enough to produce sufficient pressure on the rod to keep the necessary friction on the rod. We generally prefer, wherever it is possible, just to put on a plain funnel-shaped cup with an inch and a quarter or an inch and a half hole, if the bearing will allow it, and just put a rod inside of that and nothing more, and may be once a day a man will go around and push the grease on it.

Mr. Grant.—Our cups are made with similar wire, but no spring; our line shaft is two and seven-sixteenths, running one hundred and twenty revolutions per minute. We have one that is running nearly 4,000, and we have never touched the rod in the cups since they were put on.

Mr. Comly.—When once the lubricine is well worked in and the dirt worked out, it just seems to lie there and keep the parts from touching each other, and they run with very little friction. One of the members asked me if I had taken any cards to indicate the difference in horse-power before applying the grease and afterward, and I remarked that I had not. The decrease of temperature of the bearings would seem to be sufficient evidence that the friction was decreased.

Mr. Woodbury.—Mr. President, the cost of an oil or a grease does not represent the whole cost which should be charged to friction. With a grease, the consumption is less, and the cost of the lubricant is much less than with oil; but in those instances where I have had some personal knowledge, the friction has been increased by the substitution of the grease for the oil.

This winter I went to a Fall River mill where the predecessor of the present agent had invested $2,400 in providing all his shafts with grease cups, and was using a grease which required a further supply only once in six months. The cost of that grease was much less than oil, but he had suspected that the friction was excessive, because he learned that his mill required more power per spindle than those of his competitors. And yet he hesitated to make a change, because it would cost $1,400 to provide the journals of those shafts with oil cups, and he would have to abandon the grease cups, making $3,900, in dead plant upon the oil and the grease cups. In one side of the card-room in the hangers of the line of the shafting, the grease cups were removed, and oil cups were run in their place. After it had been running for some time, I made some observations and found that

upon one side of the room where the shafting was lubricated with oil, the temperature of the frictional surface in the hangers was only eight degrees greater than that of the room. On the other side of the same room on a similar line of shafting running the same amount of machinery, doing the same work, and under the same supervision, but lubricated with grease, the heat of the frictional surface in the journal was 38 degrees greater than the temperature of the room. Now, that excess of heat means, of course, that the work of the engine was converted into heat, and it is certainly an expensive way to warm a room. (Laughter.) And of course it also represented an additional amount of coal under the boiler. The frictional surface was moving at the rate of about 175 feet a minute, and the pressure was 14 pounds to the square inch. I took samples of the oil away and tried them on an oil-testing machine which I have of my own make, and found that the friction of the grease at 128 degrees, 14 pounds pressure, 175 feet a minute, was 33 per cent. greater than the friction of the oil at the same pressure and velocity, and at a temperature of 98 degrees. Supposing that difference would hold good, it would warrant almost any expenditure in changing the oil cups and in using oil in place of grease. However, in using a grease or any lubricant, of course it is necessary to use one whose viscosity is enough to enable it to adhere to the surface of the metal. If the journal is rough or out of line or the pressure or velocity excessive, why, as a lesser evil, then a grease or a less fluid oil must be used. In the case of Mr. Comly's, a 26 Beaumé gravity oil was a rather light oil to use upon the engine. A 24 Beaumé is what is more generally used. In the light pressure journals used in cotton manufactories, there has been a great change to the lighter oils, within the last few years, because the diminution of friction warranted a greater expenditure of oil. One of the mills in Manchester, N. H., was operated by a water privilege which they were using up to their full limit. They changed their oil from about 28 to 32 Beaumé, and the diminution of the friction was so great that the mill ran and the production increased five per cent. In another mill where I advised a similar change, by substituting a mixture of paraffine oil and sperm for a mixture of paraffine oil and lard, the difference was so much that the agent of the mill said he didn't know what "co-efficient of friction" meant, but he followed my advice, and found that he could run his mill with his water-wheel gate partly shut. (Laughter.)

Had I fully known that this question was coming up in this form, I should have certainly brought some of my note books with me; but I trust that by the time of the next meeting you will make observations upon your own account, noting the cost and the quantity of power in connection with the cost and the quantity of the lubricant. For the heavier bearings and those running at excessive velocities, why, the heavy greases which are in use are the only method in which the work can be safely lubricated. (Applause.)

Mr. Comly.—In the use of lubricine and othes greases such as I mentioned in my paper, I will state that I have applied them to heavy machinery and line shafting and in warm places around engines where oil would run off quickly. It is not advisable to use heavy greases on *very light* running machinery, such as Mr. Woodbury refers to, namely, cotton mill machinery, etc. I quite agree with him in the importance of using light oils for such light work. The application of lubricants to machinery requires very careful management in order to obtain the most economical result, and it is equally as important to consider the saving of *power* as it is to consider the saving of lubricant. Care should be exercised to take both into consideration in choosing the proper lubricant for the various kinds of machinery, and always keep several grades of oils and greases in store with the strict understanding that *light* oils shall be given out for light running machinery, and heavier oils for certain other heavier machinery, while the greases or lubricine for still heavier machinery and shafting.

SOME OF THE MECHANISM EMPLOYED IN MULTIPLEX TELEGRAPHY.

BY

THOMAS WHITESIDE RAE, C.E., NEW YORK CITY.

THERE is a peculiar embarrassment attendant upon the preparation of a paper such as this, resulting from uncertainty in regard to its audience. One composed solely of specialists, versed in the elements and details of electrical mechanism, and only interested in new adaptations of them, must needs be impatient of explanatory descriptions which a physicist familiar with electrical laws and their mathematical demonstration, yet ignorant of the parlance of the operating-room, would esteem of material aid to his comprehension of the subject. Between these extremes is another class which, although unread in the vernacular of electricity, and comparatively indifferent to its scientific abstractions, is yet interested in that practical reconciling of its incompatibilities with common needs which raises it to the rank of a public utility, and a living force in the economy of life. To such an audience this paper is addressed.

Its province will be limited to brief historical notice of the conception of the idea of multiplex telegraphy, and of the important steps in its development: to a statement of the general problem in its several phases and their solution; and, finally, a concise description of the systems in widest present use, and their working.

The motive of research in this direction has been—as is true of nearly all cases of material progress—financial profit. The point is soon reached in any telegraphic conductor—dependent upon its conductivity, induction, and the skill of its manipulator—which is the ultimate of its power of transmission; and this had been some time attained—so far as existing conductors and instruments were concerned—when in 1853, Dr. Wilhelm Gintl, Director of Austrian State Telegraphs, conceived the idea of simultaneous transmission in opposite directions; thus doubling the capacity of his lines for business, with little or no additional expense for plant and equipment. He achieved certain encouraging results, but failed of complete success through an inadequacy of his method which it is needless to particularize here. Justice requires it should

be said that our own fellow-member Mr. Farmer antedated Gintl by a year in the quest for multiplex transmission, and it is only for the reason that he chose another path than the one whose persistent following has led to the successful working of the present day, that more extended mention is not made of his initial investigations. He also experimented successfully at a later day in the direction which Gintl pointed out.

Gintl's lead, although seemingly to no purpose, was taken up in 1854 by Carl Frischen, Inspector of Telegraphs in Hanover, and so well prosecuted that duplex telegraphy may be said to have sprung full-grown from his brain. Whatever has been done since, so far as single transmission in opposite directions is concerned, is, almost without exception, mere detail. His demonstration of the general problem is typical of all, and the basis of the methods in successful operation to-day. The conditions of the questions are, succinctly, that the receiving instrument at the near station shall—contrary to former practice—remain unaffected by movements of the transmitting key at that station, and yet be perfectly free to respond to currents sent from the far station, which must also find instant and unimpeded escape to earth. Figure 1, shown in a perspective which, so far as I am aware, has not yet been classified by any school of mechanical drawing, exhibits the *motif* of Frischen's solution

Before entering upon explanation, it may be of service to invite consideration of a few definitions which are the more necessary since even professional experts are at variance about them. For example, there is confusion in regard to positive and negative currents, positive and negative poles, and the positive and negative elements of a battery cell. Let it be understood that the electro-positive element is that which chiefly undergoes chemical decomposition, and the electro-negative element the one to which the products of chemical action tend and attach themselves. As a consequence, the current within a battery cell is always from the electro-positive to the electro-negative element. The current maintains its direction *without* the battery, and it greatly assists a comprehension of its behavior to associate the terms positive and negative with the idea of motion, *i.e.*, that the current moving *from* the cell is always positive, and the one moving *toward* it always negative. Corollary to this is the seeming paradox that the positive current takes its departure from the negative element of a cell, and *vice versa*. The substitution of the term *electrode* for *pole* favors

precision; and the understanding that the positive electrode is attached to the negative element of a cell, and the negative electrode to the positive element, may simplify description.

Fig. 1 gives a representation of one of the most prevalent devices in electrical mechanism—the electro-magnet, commonly called a relay. It is the chief dependence for opening and closing circuit at a distance, conveying and recording a signal, or maintaining a vibration, and derives its force from a current being conducted continuously around it in the same sense, and normally to its axis. This imparts polarity to the core, and it becomes a magnet. Frischen did not discard this device, but—bearing in mind the first condition of his problem, viz., that the receiving instrument at the near station should remain unaffected by movements of its own key, yet sensitive to impulses sent from the far station—divided the conductor encircling the relay-core, winding each half in a contrary direction. Now when the key *K* is depressed, the current from the battery *B*, connected with earth at *E*, passes along 1, *K*, 2, to *c*, where, each branch offering a path of precisely the same resistance, it divides equally and passes around the relay-core, equal in quantity and tension, but in opposite directions, each neutralizing the effect of the other, and leaving the relay quiescent. Thus the first condition is met. Of the divided current, one-half passes along the line *L* to the far station, making signal there, and the other goes through the variable resistance *X*, to earth. This resistance is equal to that of the line, and preserves the accurate balance needed for the working of the divided relay. It is made adjustable, to meet the varying condition of the line, instruments, etc., etc. This apparatus receives a signal in this manner. With K open, as shown in Fig. 1, a current arriving at R, from the far station, would pass through one coil of the relay, cause it to make signal, and find its path of least resistance to earth by way of *c*, 2, *z*, 3, *E*. With *K* closed at 1, the course would be *c*, 2, *K*, 1, *B*, *E*.

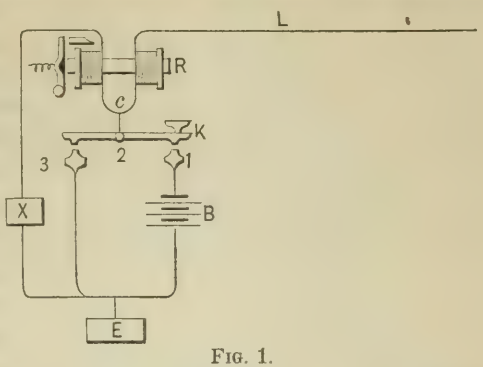


FIG. 1.

Fig. 2 shows two stations connected for transmission in opposite

directions by Frischen's method. The batteries B, B have their positive electrodes to the line L, and their negative electrodes to earth E. R and R' are the receiving relays wound with divided coils already described. The resistances for adjustment, X and X', are regulated so as to equal in amount the resistance of the line L plus one coil of the relay at the far station.

Now, when the key K at station A is depressed, the current from battery B will divide at 3, one half passing by 4, and 5 to to the line L, through one coil of the distant relay R', causing it to make signal, and thence by IV, III, II, to b' of the key-lever K' and c', XI, to earth E'. The other half, starting from 3 at station A, will follow the other coil of R by way of 7, 6, 8, X, 9, 10, E. These two branches of current will have been of equal and

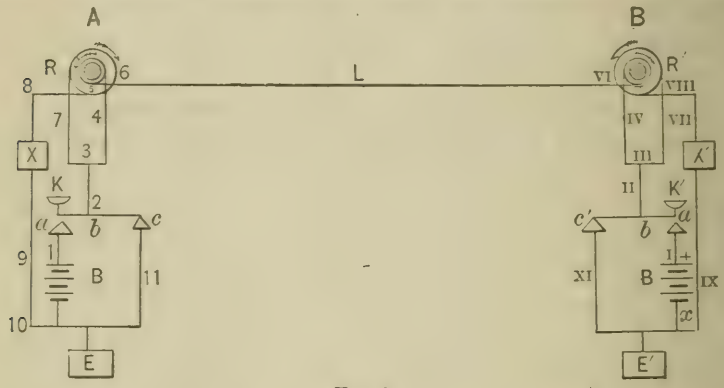


FIG. 2.

opposite effect upon R, which will have remained neutral, while R' influenced by the passage of a current through but one of its coils will have responded and made signal. If it had happened that K' at B had been depressed simultaneously with K at A, the portion of current entering the line from each station meets an equal and opposed current producing a condition of neutrality between the dividing points 3 and III. The other portions of current at both stations pass about their relays to earth—or rather, complete their circuits—through 7, 6, 8, X, 9, 10, and VII, VI, $VIII$, X', IX, X respectively, making signals as they go, each corresponding to the movements of the key at the remote station.

There is another condition of circuit which exhibits the system at its worst, but which does not practically interfere with its usefulness. It is when the key at one station, for instance B, is midway in changing from rear to front contact—c' to a'—and *vice versa*. In

this position the current from *A*, having passed through the first coil of the relay, is arrested at *b'* and continuing by way of *VII*, *VI*, through the second coil, finds a path to earth by *VIII*, *X'*, *IX*, *X*. The electrical balance of the system is disturbed by the arriving current having to encounter a double resistance; for example, the addition of *X'*; but its effect on *R'* remains practically the same from its now following both coils of the relay; the influence of the halved current through the double coil being equivalent to that of the whole current through a single coil. The only detrimental result of this is that the derangement of electrical balance will affect, in some degree, the relay at the starting station; but in practice this has been found inconsiderable except at an unusually rapid rate of transmission.

Frischen's system, with unimportant modifications by various experimenters, maintained a feeble hold upon the public attention until 1872, when, after some years' study, Mr. Joseph Barker Stearns, of Boston, imparted new vitality to it by several additions, one of which effectually disposed of the prime obstacle to its general use and vastly extended its scope of operation. The difficulty was one inseparable from all conductors, all of which have a definite capacity, and, once charged, tend to discharge themselves by every exit available. Illustrating by Fig. 3, it can be readily seen that when, at the termination of a signal, the transmitter *T* establishes connection at the sending station between the line and earth, through the contact *c*, the former will tend to discharge itself by this channel as well as by the earth-connection of the distant station, and, passing, perforce, through but one coil to the relay, *R*, will produce a false signal which would interfere seriously with those arriving from the far station. In short circuits—within 400 miles of average air-line—this was not of much moment, but it effectually limited the application of double transmission to that distance.

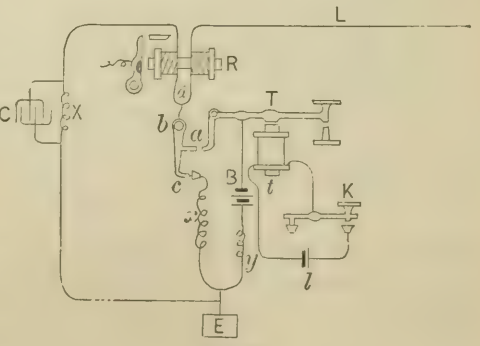


Fig. 3.

Stearns met the difficulty by interposing a condenser of the usual construction and of a capacity equal, at least, to that of the line, and as much more as experiment proves necessary. Such an one is shown at *C* in Fig. 3, and, with each signal sent through the line, receives through one half-coil of the relay, an equal amount of charge, which finds its way back by the same path when the transmitter again makes its earth contact at the same instant that the return discharge from the line is passing through the other half-coil, thus preserving the neutrality of the relay as perfectly as need be.

Another addition of Stearns—which, however, can hardly rank higher than a convenience—is the transmitter *T*, which is controlled by a key *K*, local battery *l*, and electro-magnet *t*. The first motive for introducing this was to avail of the possibility of reading by sound which it affords; but experience has shown that it also considerably increases the rapidity of transmission, besides sparing the operator much fatigue. With every depression of the key *K*, the electro-magnet *t* becomes active, and a current from the battery *B* passes through the transmitter lever which makes contact at *a*, at the same instant breaking it at *c* through oscillation of the

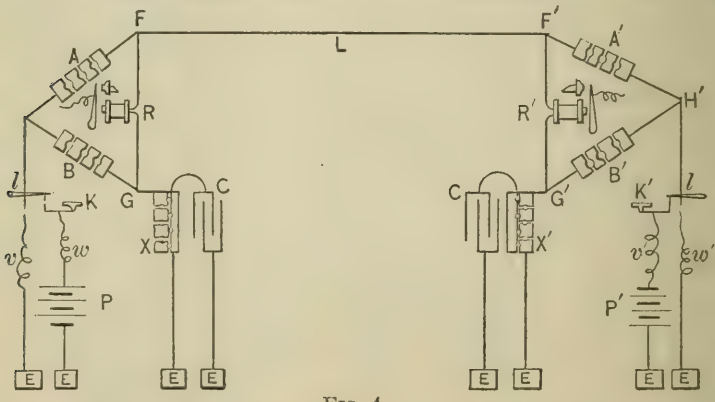


Fig. 4.

swing-bar about *b*, and passes in equal portions to line *L* and condenser *C* as before. The resistances *X*, *x*, and *y* are introduced to balance the circuit with as great facility and precision as possible.

Where this device has been employed with submarine lines, it has been found that some modification of it is necessary. This consists in largely increasing the condenser capacity and interposing resistance between it and the branch circuit, for the reason that the con-

denser discharges itself so much more quickly than the cable. To insure distinct signaling, the discharges must be equal in duration as well as in amount. The foregoing arrangement of Mr. Stearns, which he denominates the "Differential Duplex," is substantially that operated by the Western Union Telegraph Company; but he has a further development of double and opposite transmission which goes by the name of the "Bridge Duplex," and is shown in Fig. 4 as used by the same corporation. The illustration omits the transmitter—which is a customary attachment, but is inessential to a comprehension of the system—for the sake of simplicity. A description of one end of the circuit serves for both, and P, K, and l are respectively battery, key, and contact-lever; A and B adjustable resistance coils; GF the bridge and R the relay; X a variable resistance; C the condenser; w and v small resistances simply to save the battery the wasteful "short-circuiting" which may accidentally befall it while in action.

If resistance A stands in the same ratio to that of the line L, that resistance B does to X; when the key K is depressed the current will divide itself equally between these two paths, and the bridge and relay R be undisturbed. In the case of a current arriving from the far station, it finds two exits open to it—one through A, l, and v, or w, and P to earth; the other through R and X, or B, etc.

When several paths are open to a current, it apportions itself among them in inverse ratio to their several resistances, and adjustment of these for the case in question will invite the proper amount of current through R to produce the most effective signal. Here, as before, the corner-stone of the system, the condenser, plays its indispensable part, but while several distinct advantages over the differential method are conceded to it, its much less scope with equal battery power precludes its employment on long circuits.

Frischen's success with double transmission in opposite senses stimulated search for it in the same sense, and in 1855 Dr. T. B. Stark, of Vienna, solved the problem. His demonstration is given in Figures 5 and 6, showing, respectively, its arrangements at a sending and a receiving station. In the first case, Fig. 5, K and K' are two keys, the latter having at its rear a movable insulated earth contact which it presses at will against the anvils 5 and 6: otherwise the key is of the common pattern with all customary contacts and connections; 1, 2, and 3 respectively. There are two batteries, B and B',

the latter having double the number of cells of the former, and being controlled by key K', while B is controlled by key K. The connections are sufficiently evident to require no enunciation, and will be made clearer by remembering that the long thin lines in the group of parallels representing the batteries signify the copper plates and the short thick ones the zinc.

When K is depressed the current of B is from earth, E, through

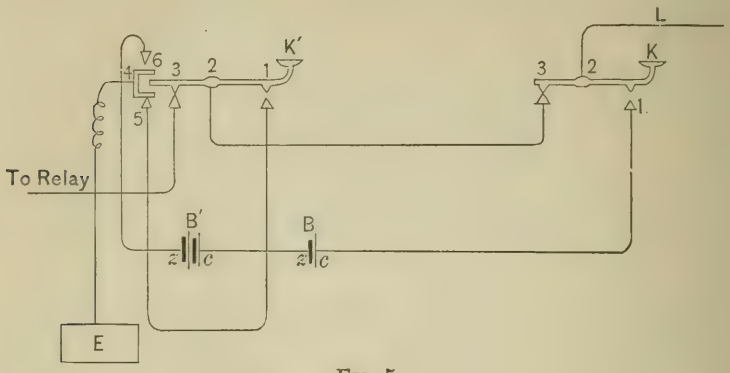


Fig. 5.

4 and 5 of K', across the post between the batteries, to z and c of B, 1 and 2 of K and on to line L. When K' is depressed the current of B' is from earth E, through 4 and 6 of K' and z, c of B' to 1 and 2 of K', and thence by 3 and 2 of K to line L. If both K and K' are depressed, the combined current of B and B' is from earth, E, by way of 4 and 6 of K', through both batteries and 1 and 2 of K to line L.

The foregoing three conditions of circuit produce as many currents whose intensities stand in the ratio of 1, 2 and 3, and which may be designated by Z, Z_1, Z_2. Their behavior at the receiving station, Fig. 6, will be as follows: Primarily, all currents pass through the relays R and R' which are actuated by a local battery B whose zinc pole connects with their levers and copper pole with their lever anvils. The relay R' has an additional coil, enveloping the first, in circuit with a resistance X and another local battery B' which is controlled by the lever of R. This lever is drawn to its contact by a spring which is so adjusted that, while it is insensible to the current Z, from the lesser battery of the transmitting station, it is affected by that of Z_1 from the greater battery or by Z_2 from both combined. The other relay R' is adjusted to respond to a weaker current as Z, consequently the depression of the key K at the far

station sends the weakest current, Z, through the line which continues through relay R without affecting it, but causes the more sensitive R' to close the local circuit including W', battery B, sounder S', etc., making thereupon the signal given by K.

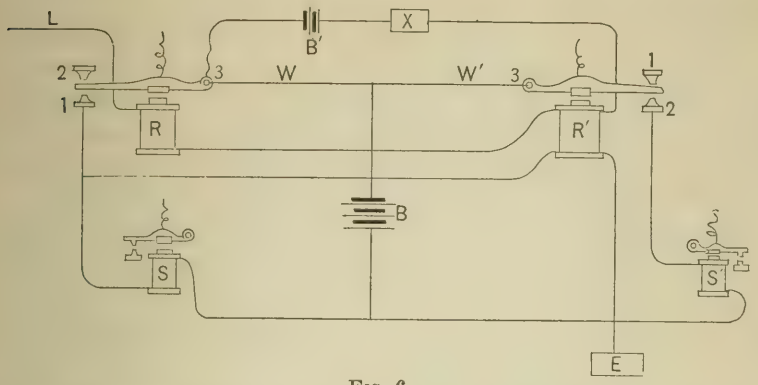


FIG. 6.

Should K' be depressed, the stronger current Z_1 flows and the lever of R makes contact at 1, closing the local circuit which includes battery B', resistance X and the additional coils of R' thus neutralizing the effect of the line current upon R'; since the batteries B' at both sending and receiving stations are of equal intensity and their currents traversing the double coils of R' in opposite directions become of no effect. The circuit including sounder S' being thus left open, it makes no sign. The movement of R which brought B' into action also completed a circuit including W, battery B, sounder S, etc., causing the latter to deliver the signal transmitted by K'.

The only other condition possible is when K and K' are depressed simultaneously. This sends the combined current of both batteries at the sending station, B and $B' = Z_2$, though both relays R and R' and the former as before closes the local current including B as well as that of the counteracting battery B'. The sounder of the first makes signal as a matter of course; and as for that of the latter, since we have seen that the intensity of the counteracting current about R' is only equal to S_1 and as S_2 traversing the other coil of R' is by construction equal to Z and Z', it is evident that R' will be actuated by a current equivalent to their difference, or Z, for which it is adjusted and which is the same that influences it when K alone is depressed. The circuit of R'

being thus closed, its sounder S makes the signal corresponding to the motion of the key K at the far station.

This handling of the question has disposed of all difficulties which are not, in our present state of knowledge, inseparable from the system; and, in fact, of all which are not, of necessity, insurmountable in the opinion of the most experienced and farthest-seeing investigators of the day. That of interruption caused by one key being midway between front and rear contact at the same instant the other is depressed may be cited as one of these as well as the interference arising from rapidly succeeding states of positive and negative electrification of the receiving instruments. For neither of these does there seem to be a remedy.

The successes thus far chronicled served to lead up to that seeming *non plus ultra*, the quadruplex system, or sending simultaneously over the same wire four signals, each pair in contrary directions.

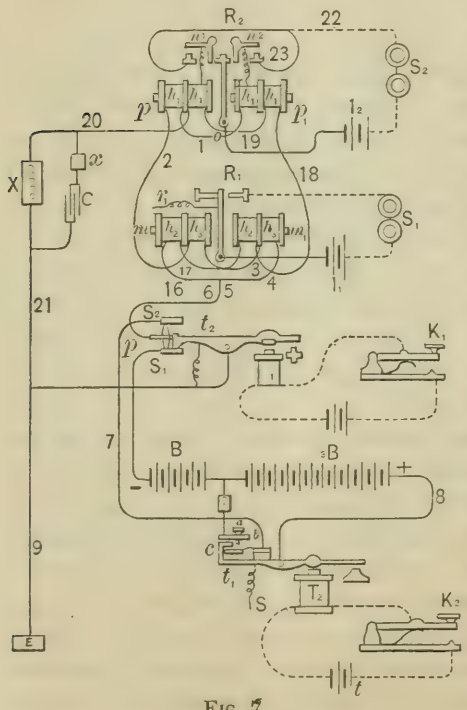


Fig. 7.

Fig. 7 shows the arrangement in widest general use, which is principally due to the genius of our fellow-member Edison. Quadruplex telegraphy is not a mere combination of the two methods of double transmission heretofore described. It has been found, necessary to employ two different principles of instrumentation designated the "double current" and the "open current." The former keeps the battery of the sending station in permanent connection with the line; signals being given by reversing the line current without breaking circuit. The relay which responds to these reversals differs from the ordinary type, in having a permanently magnetized armature and having no adjusting spring; its action being due to the nature of the

current and not to its strength. In the "open current," or single current system, signals are made by opening and closing circuit, or by increasing and decreasing a current, and are given by a relay with a neutral armature and a retracting spring. In the latter system, intensity of current is the sole agent. With these divers properties of current as a means, quadruplex telegraphy became possible. In Fig. 7 the receiving portion of the mechanism is, viz.: R_1 and R_2, differential relays with polarized armatures—the ordinary neutrally armed relay has been ultimately quite superseded; it having been found that the "differential" was of more convenient application than the "bridge" method—S_1 and S_2; the sounders and l_1, l_2, the local batteries. The transmitting portion is, viz.: K^1 and K_2 the keys with their local batteries; T_1 and T_2 the transmitters; B and 3 B, the main batteries. The resistances, X and x, the condenser C, and the earth plate E are common to both. The key K^1 effects a signal by reversing a permanent current—the polarized armature of the corresponding relay being attracted or repelled thereby. K_2 does so by diminishing the current or bringing at will both batteries, B and 3 B, or B only, into action. If, then, the ordinary plus sign be taken to mean positive and the ordinary minus sign negative, the intensity and character of the current pervading the circuit in every possible status of the instrument will be as follows:

K_1 open	K_2 open	+ 4 B.
" closed	" "	− 4 B.
" open	" closed	+ B.
" closed	" "	− B.

In the first position the positive current of both batteries flows to the line via earth E, 9, t_2, contact spring S_1; batteries B and 3 B, 8, t_1, c, b, 7, contact spring S_2, post p, 6, etc., and the polarized armature o of the relay R_2 is drawn against the contact lever n_1, and away from n_2, breaking the circuit of sounder S_2.

In the second position the line current is reversed, coming to earth E by way of 6, post p, contact spring S_2, t_2, and 9; and the armature o is impelled against n^2, again breaking the circuit of the sounder S_2, and consequently it remains unaffected by the stronger currents, whether positive or negative, which make signal on the relay at the far station corresponding to R_1.

In the third position the current intensity, no matter what its

polarity, is reduced from 4 to 1—by being given an earth connection by way of *a*, *b*, 7, etc., between the two batteries—and the springs of n_1, n_2, are too strong for it wherefore the local circuit of sounder S_2—or rather the one corresponding to it at the remote station, for the differential relays heretofore described are uninfluenced by the outgoing currents of their station—is completed through the double contact of armature *o*, and it obeys the indication of K_2.

The fourth position requires no further explanation, and in general terms the arrangement is such that R_1 is unaffected by the weak arriving currents, and its sounder S_1 is therefore quiet, while the stronger currents automatically eliminate S_2 from the train, only allowing it to respond to the lesser current, as already rehearsed.

The latest prominent example of multiplex telegraphy is that known as the Harmonic system, devised by Mr. Elisha Gray, of Chicago, in 1873. He discovered, in the course of his experimenting, that the vibrations of a musical reed in electrical communication with a charged conductor would produce synchronous movement in a vibratory surface at its remote end, keyed to the same tone as the reed, and in only such an one. The receiving instrument of this system is a thin metallic band stretched tightly between posts—by means of an adjusting screw which tunes it to any desired note—in front of the poles of an electro-magnet, which is traversed by the current pervading the vibrant reed and the line. The electro-magnet and metallic band are mounted on a thin resonant open box, which gives intensity to the tone, as does the body of a violin or guitar. So long as the reed at the sending station is vibrating and the current passing over the line, the resonator at the receiving station emits a continuous tone, which the key at the sending station breaks up into the dots and dashes of the ordinary telegraphic alphabet. Theoretically, the messages which can be sent simultaneously over one wire depend only upon the number of vibrant reeds and of resonators in circuit. In practice, eight messages, four in each direction, have been sent over circuits of one hundred miles and upward without any interference. Fig. 8 shows how the continuous vibration of the reed is secured. The reed *a* is fixed in the post *b* by one end, and vibrates under the influence of the electro magnets *e* and *f*, whose resistances are proportioned about in the ratio of 1 and 7 respectively as the result of experimental teaching.

Both are in circuit with a local battery B, and the one of greatest resistance, or longest helix, is naturally most effective. Throwing its resistance out of circuit would also intensify the other by permitting more current to flow through the latter. If, therefore, the local battery B^1 is brought into action by making a plug connection

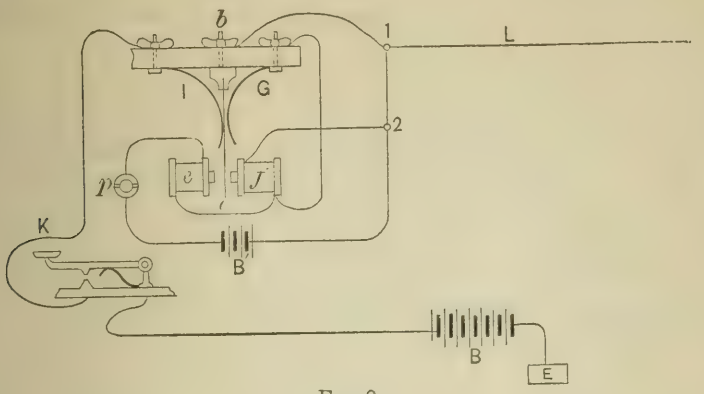


Fig. 8.

at p, its entire current will first pass through the magnet e alone, as f is shunted by the loop from contact spring G, resting against the reed, which offers a path of less resistance, and the current follows 2, 1, b, G, loop, etc. The action of e upon the reed a withdraws it from G, breaking the short circuit and bringing f into play, which, being the stronger magnet, again establishes contact with G, and again cuts itself out of circuit. This alternate action is maintained so long as the local current flows and the reed vibrates in conformity with it. If the vibrating reed a be put in electrical connection with a line wire L, via contact spring I, and a current from battery B be sent along it by depressing key K, the resonator of the same pitch—and only that one—at the far station will emit the same note; which the key K divides into conventional signals. Fig. 9 shows the method of connecting several reeds in telegraphic circuit. A' and B' are the reeds, the vibrating mechanism being omitted to avoid confusion. Each transmitting key, etc., is placed in a loop circuit around its own battery, and the main circuit runs through all, which is a feature of importance in obtaining the intensity of current which the system necessitates.

In conclusion, it only remains to say that the commercial value of such discoveries as the foregoing to telegraph companies, while exceedingly great, is not all that would appear at first glance. The

first inference on hearing that the working capacity of a line had been increased eight-fold would be that the profits were swelled in the same ratio, but this is not the case. To the credit side must be placed, of course, an eight-fold increase of receipts and a diminution to one-eighth of the charge for interest on cost, deterioration and supervision of a system of ordinary type and of equal capacity. Assuming that the average cost, in this country, of a mile

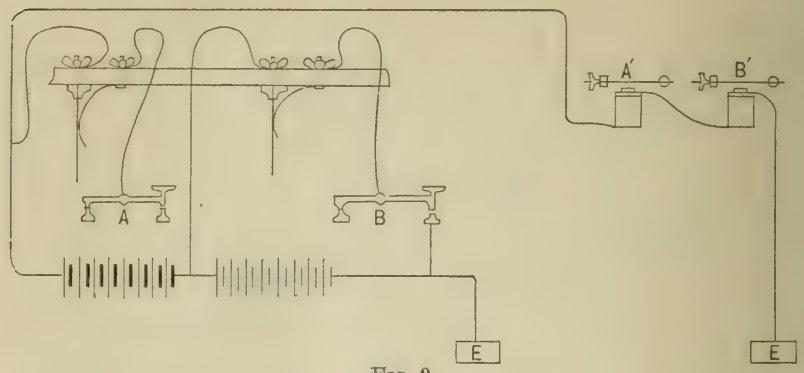


Fig. 9.

of well-built telegraph line is $250, its mean life-time fifteen years, and that the annual cost for inspection and repair is—which is the case—insignificant; the latter item will not amount to much. On the debtor side must be set down the salary of an additional operator for every time the capacity of the line is increased; since each transmission and reception requires the undivided attention of a clerk. The equipment of a station is also very much increased in cost. There has been, however, no radical increase in the rate of pay of the office *personnel* since the introduction of multiplex telegraphy, and if the existing scale left a reasonable profit in the days of single transmission, it is clear that stockholders in telegraphs are losing nothing under the new system.

SPIRAL SPRINGS—COMPRESSIBLE AND TENSILE.

BY

OBERLIN SMITH, BRIDGETON, N. J.

Springs, using the word in the mechanical sense only, may be broadly defined as devices to store up power by means of the elasticity of matter. A convenient general classification would divide them into *fluid*, *semi-fluid* and *solid*. The first are, of course, compressible only, and the strain put upon them seems to be merely the crowding closer together of the molecules of a perfectly elastic substance, as air or other gas, in a state of confinement. In what we here call semi-fluid substances, of which india-rubber is perhaps the most notable example, the action appears to be somewhat of the same character, when the material is confined, but to consist chiefly, when not confined, of a very considerable distortion of shape, with a corresponding violent flow of its particles among themselves. In solid springs the particles approach, recede from, or slide past each other, to an amount within a fixed (the elastic) limit, precisely the same as in other solid structural members when subjected to stress. This stress is usually compressive, tensile, lateral or torsional—as regards the spring itself. Relatively to the piece of material of which the spring is composed, the stresses can of course all be resolved, as usual, into compressive, tensile and shearing.

In all the varieties of "flat" and "elliptical" springs the stresses are respectively compressive and tensile on either side of the "neutral line," exactly as in any other beam or lever. Belonging to the same class, but with modified conditions of leverage, are "coiled" (or flat spiral) springs, such as are used in watches, etc., and also such helical spiral springs as are used torsionally, examples of which may be seen in ordinary locks, in mouse-traps and for shutting doors.

It is, however, the object of this paper to treat only of such spiral springs as are strained in the direction of their axes, by either tension or compression. These are usually helical—that is, in the form of a cylindrical coil. The word "helical" would, in fact, have had a more exact meaning than "spiral" in the title of this

paper, as it does not include flat-spirals, but the latter word was used because it is the more popular and better known for the class of springs in question. The popular and expressive terms "push-springs" and "pull-springs" will herein be used for springs subjected respectively to compressive and tensile stress.

In designing machinery there is frequently a choice between the use of a spiral and some other form of spring. The former is undoubtedly preferable wherever it can be used to as good advantage. It has the merits of cheapness, beauty, compactness, durability and a capacity for uniformity of strain, not usually possessed by other springs. The push-spring is of course the simplest kind, and most desirable to use in cases where either push or pull can be applied to obtain a certain result. Where, in any structure, there happens to be already a hole within which, or a rod upon which, it can slide, it is the cheaper as well as simpler of the two. It has, however, the slight disadvantage of being liable to wear against its inside or outside guiding surface. This the pull-spring is not subject to, and in this respect is undoubtedly superior to all other forms of spring. Of the two most generally used methods of making the hooks at the ends of a spring of this kind, namely, bending the wire itself into a hook or reducing the coils in diameter and closing them around a separate headed hook of larger cross section, the latter is certainly preferable, especially if the spring is subjected to any swinging action which tends to wear the hook.

Regarding *methods* for coiling spiral springs, I call to mind three in common use. One is to wind the wire into a spiral groove, of the proper section to fit, turned in a mandrel. This is, however, an unnecessary trouble and expense, both in the construction of the tool and in getting the spring off of it. A second and just as satisfactory method is to wind upon a plain cylindrical mandrel, obtaining the requisite pitch of spiral by "feeding" the "tension grip" through which the wire passes along upon the carriage of an engine lathe, or equivalent tool. This is a cheap and convenient plan for machine-shop practice, where comparatively few springs of a kind are required. In cases where large quantities are required there is applicable a third method, which consists of forcing the wire through a spiral die by means of feed rollers. This delivers the springs in indefinitely long pieces.

In regard to *material* for spring wire (say of one-half inch diameter and below), there is probably nothing, on the whole, so satis-

factory as hard-drawn brass. For a cheaper article, hard-drawn iron and steel is good. Of course, more strength and elasticity can be obtained with the same weight of metal by using a tempered steel spring. The latter are not, however, as dependable as the others, on account of being liable to "temper-cracks" and unevenness or too great hardness of temper. They are undoubtedly best in many large springs (as car-springs, etc.), and in all cases where it is desirable to save room and dead weight. The popular prejudice in favor of "steel" springs is, I think, often caused by the prejudiced persons having been troubled with softer springs gradually "setting" under their load in consequence of improper design—there not being enough metal in them to allow of its strains being kept far within its *elastic limit.*

In respect to the *theory* governing the action of spiral springs, very little seems to be popularly known. It is a singular fact that few of the best known engineering books say anything about it. Having had occasion for some years past to make numbers of miscellaneous springs, I have endeavored to find some better principle to work upon than the time-honored "cut-and-try." A search through a number of works that happened to be at hand, by Rankine, Clark, Molesworth, Weisbach, Haswell, Nystrom, Trautwine, etc., revealed nothing but a few empirical formulæ regarding safety-valve and car springs—no principles being given. (It is but fair to state, however, that in some of their works Rankine and Weisbach do treat briefly the theory of the matter in question.)

A correspondence with some eminent experimentalists upon strength of materials elicited no information. Communication with various spiral spring manufacturers only developed the fact that this was entirely *out of their line*, and something in which they seemed to take no interest.

While studying this subject some time ago, the fact was pointed out to me by a friend that the action upon the wire (the word "wire" is herein used in a technical sense, regardless of its size or shape) of a spiral spring, while it is being extended or compressed, is almost purely *torsional.* Since this paper and some of the experiments below mentioned were commenced, I have seen a small book by John Perry, C.E., lately published by Cassell, Petter & Galpin, in which several pages are devoted to spiral springs, and this torsional action is demonstrated. Credit is given by the author to Prof. Thomson, of Dublin, who, it seems,

wrote upon the subject as long ago as 1848. The law of this matter is briefly thus:—When a *spiral spring* is extended or compressed, in the direction of its axis, the strains upon the *wire* are chiefly torsional. On the other hand, when the *spring itself* is subjected to torsion, the action upon the *wire* is mostly lateral or bending. In any push or pull spring the force is, in effect, applied in the line of its axis. If the ends of the wire are bent inward, so as to run across the spring in the direction of its diameter, the points where they intersect the axis are the places where the force acts. A line from one of these points out to the centre of the wire in the end coil that is to say—the *mean radius* of the spring—is the lever by which the wire is twisted. The length of this in inches, multiplied by the force in pounds, gives the moment of torsion in inch-pounds.

Thus, to ascertain the distance which one end of a proposed spring will move with a given weight attached, it is only necessary to take a straight wire of the same diameter, length and material, and, fixing one end, twist the other end with the same weight hung from the periphery of a wheel the same size as the mean diameter of the proposed coils—noting, of course, the distance moved by the weight. The results thus obtained are usually sufficiently correct for practical use, although there is a small element of error, because the action upon the wire is not wholly torsional—also from a change in the elasticity of the metal due to bending. The first-mentioned error would be *nil* if the coils were perfectly flat, but in proportion as they vary from this form, in conformity to the pitch of the spiral, there is a slight bending action in addition to the twisting.

To illustrate roughly the torsional action we have been considering, I hold in my hand a piece of lead rod about one-half inch in diameter and four and a half feet long. The ends are bent at right angles to form levers by which to twist it. It is painted black, with a narrow bright line scraped upon it along one side, in the plane of the axis. Here in my other hand I show a precisely similar piece coiled into a spiral three inches in diameter—the mean radius being the same length as the bent ends of the straight rod. This latter I now twist through an angle of 540 degrees, or one and a half times around, making the bright line appear as a spiral which records the maximum permanent twist. Lead was chosen in this case as having a very low elastic limit, so that it might "set," and thus record the strains. I

now extend the coiled rod to a setting distance of 14.13 inches, which is the distance the bent end of the straight rod traveled in going one and a half times around. I now uncoil the spiral, and if I succeed in bending it out without any torsional motion, the bright line will be found to be a spiral about the rod, closely resembling the line upon the other one.

I have recently made over 200 experiments upon pairs of specimens—one of each pair being straight and the other coiled. Both of a pair were of the same length, and were cut from adjacent portions of the same piece of wire. The amount of elastic angular motion produced by a given *moment*, in twisting rods of the same length, is, as is well known, inversely in proportion to the fourth power of their diameters. With different lengths it is directly as the length. This and other facts connected with torsional stress are the foundation of the various formulæ pertaining to spiral springs. These are proved more or less approximately by the 212 experiments recorded upon the large sheet I hold in my hand. This a careful averaging would no doubt show. Such discrepancies as remained could be accounted for by the small factors of error mentioned above, and by the difference of elasticity in the different specimens. As stated before, each one of a pair were contiguous in the original coil, but the pairs were of different sized wire, bought at different times—mostly from the same maker. The material used was chiefly hard-drawn brass. A few specimens were, however, of phosphor-bronze, soft iron, soft steel and tempered steel. The apparatus used for the coils was simply a fixed hook above and a hook below attached to a scale-pan for the weights. For the straight specimens an old lathe head, with very small journals to reduce friction, was fitted with a drill-chuck for gripping one end of the wire—the other being gripped by a special vise with "vee" jaws. Around a pully upon the lathe spindle ran a thin brass band, to the free end of which was attached the scale-pan. (It may be incidentally remarked that the lathe head used was one made by the writer many years ago when a boy novitiate in this very city of Cleveland.)

I had hoped to be able in this paper to present a tabular list of a part of these experiments, as well as a number of practical formulæ deduced from them and proved by actual trial. They should of course contain factors for correcting the errors spoken of. This must remain, however, for some future paper. An unexpected call upon my time prevented the proper working out of the matter.

This fact is of the less importance, as I have already trespassed sufficiently upon the valuable time of the Society.

DISCUSSION.

Prof. Robinson.—Mr. President, I was very much interested in the matter of the paper. I think that there is forthcoming from it much valuable information on the subject of spiral springs. It seems to be a subject upon which mechanicians are too often wanting in information. I would like to call attention to the fact that Rankine has been over pretty nearly all of the field of engineering, and, as we generally suppose, has overhauled the whole matter from one end to the other. We generally turn to him to find anything. I think it was stated here that the formulas for spiral springs were not found in several authorities, Rankine being included.

Mr. Smith.—The volume of Rankine that I had at hand was the one on "Applied Mechanics," but I did not search through all his books. I believe, as I said in the paper, that he does say something about it somewhere, but not at any great length.

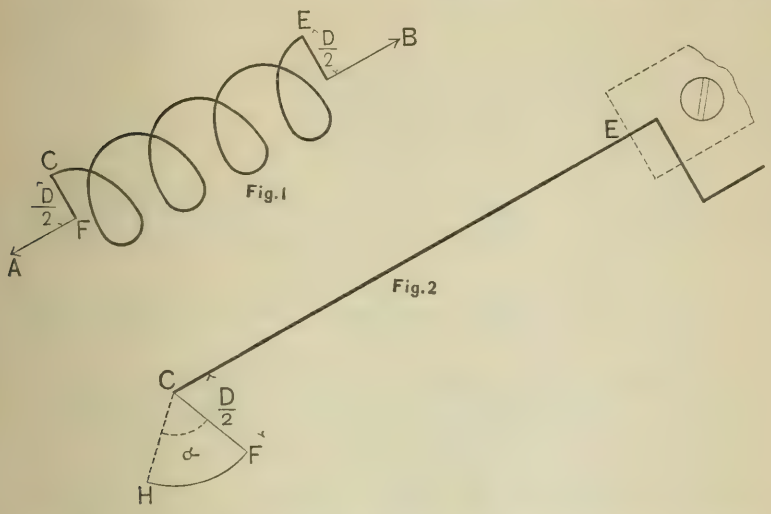
Prof. Robinson.—If we assume that he has overhauled the whole field of engineering, we would naturally expect to find something on spiral springs. In his "Machinery and Mill Work" we find the formula given. It is not deduced there; it is simply stated But I have examined it myself carefully, and find it to be correct, the reasoning by which the formula is deduced being exactly that given by the paper. The subject-matter leading to this result I have been in the habit of giving to my classes every year in a manner which I can illustrate on the board in a few moments. Suppose the spring to be constructed as has been illustrated by Mr. Smith, and as shown in the sketch, Fig. 1, the line AB being the axis of the helicoid.

Now the formula of Rankine is just as though this helicoid of Fig. 1 were regarded as straightened out, as shown in Fig. 2, and the portion CE treated as a torsional piece and the formulas for torsion adapted to it. To illustrate further, let CE, Fig. 2, be regarded as a straight wire of the same length, size and form of section as the wire composing the helix CE of Fig. 1. Also let CF, Fig. 2, be equal CF, Fig. 1, in length, etc., with CF at a right angle to CE.

Now, as has been fully and clearly shown by Mr. Smith, the

force *FA*, Fig. 1, produces torsion on the first short bit of the spring at *C*, reasoning which can be applied to any other small portion of the spring—indeed to the whole of it—and in the manner shown in Fig. 2.

The displacement of *A*, Fig. 1, regarding *B* as fixed, thus ap-



pears to be due to torsional elasticity, the fact being strikingly proved by the models shown and used by Mr. Smith.

Hence we are to look for the displacement of *A*, Fig. 1, in the corresponding arc *FH*, Fig. 2.

[The following has been added since the meeting, having been prepared in answer to the general invitation of the president for a subsequent forwarding of the complete discussions for use in the published transactions.]

Formulas for Helical Springs.

By aid of the considerations presented by Mr. Smith, and of the sketches of this discussion, Figs. 1 and 2, we are able to establish the formulas and rules for helical springs as follows:

Let D = diameter of the helix from centre to centre of the wire. If the wire is not round, take the centre of gravity of the cross section of wire for the centre.

d = diameter of the wire if round.

b and d = breadth and depth of the wire if it is rectangular or elliptical in cross section.

b = the side of a square wire.

I_p = the polar moment of inertia of the section of the wire.

$I_p = \frac{\pi d^4}{32}$ for round wire.

$I_p = \frac{b^4}{6}$ for square wire.

$I_p = \frac{bd}{12}(b^2 + d^2)$ for rectangular wire.

$I_p = \frac{\pi bd}{64}(b^2 + d^2)$ for elliptical wire.

E = coefficient of elasticity of the material of the wire.

E = about 30,000,000 pounds per square inch for tempered cast steel.

E = about 15,000,000 pounds per square inch for spring brass wire.

E = about 18,000,000 for spring copper wire.

R = modulus of rupture in pounds per square inch.

R = about 120,000 for tempered steel.

R = about 49,000 for spring brass wire.

R = about 60,000 for spring copper wire.

$\alpha = \frac{2h}{D}$. Where α is the arc to a radius unity, when $\frac{2h}{D} = 1$, the angle HCF = about 57.3°.

h = displacement of A, Fig. 1, or elongation of spring.

l = nearly πDn = length of the helical wire.

n = number of turns of wire in the helicoid.

P = pull or push in pounds upon the spring.

P_1 = greatest safe steady pull or push, on spring.

f = factor of safety, which probably should range from 3 to 8, according to the frequency of distortion of spring.

$\frac{R}{f}$ = greatest safe strain which the wire may be subjected to per square inch.

r_1 = the greatest distance from the centre of gravity of the cross section of the wire to the most remote edge of that section.

$r_1 = \frac{d}{2}$ in round wire.

$r_1 = b\sqrt{\frac{1}{2}}$ in square wire.

$r_1 = \frac{1}{2}\sqrt{b^2 + d^2}$ in rectangular wire.

$r_1 = \frac{b}{2}$ $\frac{d}{2}$ in elliptical wire, the greater being taken.

Then the formulas for torsion, which may be found in Prof. D. Wood's Resistance of Materials, are :

For any load.	For greatest safe load.
$P\frac{D}{2} = \frac{3}{8} E \frac{\alpha}{l} I_p$,	$P_1\frac{D}{2} = \frac{4}{5}\frac{R}{fr_1} I_p$;
or $P = \frac{2}{D}\frac{3}{8} E \frac{2h}{D} \frac{I_p}{\pi D n}$;	$P_1 = \frac{2}{D}\frac{4}{5}\frac{R}{fr_1} I_p$;
$P = \frac{3E}{2\pi}\frac{h}{n}\frac{I_p}{D^3}$.	$P_1 = \frac{8}{5}\frac{R}{fr_1}\frac{I_p}{D}$.

The greatest safe displacement, h_1 for any spring is :

$$h_1 = \frac{16}{15}\frac{\pi n R D^2}{E f r_1} .$$

When the load is suddenly placed upon the spring, causing oscillation, the greatest safe load is

$$\frac{P_1}{2} .$$

Example.—Given a tempered steel spring coiled from $\frac{1}{4}'' \times 1''$ flat bar steel with 10 turns, and to a diameter, c. to c. of $3''$.

Then $D = 3''$; $bd = \frac{1}{4}'' \times 1''$; $n = 10$; $r_1 = \frac{1}{2}\sqrt{b^2 + d^2}$;

$$I_p = \frac{bd}{12}(b^2 + d^2) .$$

Taking E and R as given and $f = 3$, we obtain

$$h_1 = \frac{16 \times \pi \times 10 \times 120{,}000 \times 9}{15 \times 30{,}000{,}000 \times 3 \times .515}$$
$$= 0.78 \text{ inch}$$

for the greatest deflection with a factor of safety of 3. The breaking deflection of the spring would therefore be $3 \times 0.78 = 2.34$ inches.

The load carried at the $0.78''$ deflection is by the formula P_1, or by the formula for P with the value $h_1 = 0.78$ introduced, found to be

$$P_1 = 916. \text{ pounds.}$$

If these results differ from practice, that is, if the load 916. pounds does not produce a deflection of 0.078″, and if the spring does not break with a load of 3 × 916. = 2,748 pounds and a deflection of 2.34″, it argues that the constants in the above formulas are not given correct values. The experiments of Mr. Smith will serve to give the desired values of the constants.

If the springs are made of round wire, the formulas become simplified somewhat.

For any load,

$$P = \frac{3E}{64}\,\frac{h}{n}\,\frac{d^4}{D^3}.$$

For greatest safe load,

$$P_1 = \frac{\pi}{10}\,\frac{Rd^3}{fd},$$

and the greatest deflection or displacement with safety,

$$h_1 = \frac{32}{15}\,\frac{\pi n R D^2}{Edf}.$$

These formulas, in substance, for round wire are found in Rankine's Rules and Tables, page 304, and other authors.

The 1st formula for greatest deflection, h_1 contains r_1 in the denominator, which is the distance from the centre of the section of the wire to the most remote point in that section. In a square wire this is greater than for a round wire of equal diameter, because in the square wire it is to be measured on the diagonal. As the other quantities in that formula do not change with the section, it appears that the deflection is inversely proportional to this distance r_1 for a spring of a given material.

Hence a spring of $\frac{1}{4}''$ square wire, for instance, will not stand as great a deflection as one of $\frac{1}{4}''$ round wire of the same material. Hence where a large deflection is the only object, round wire is the better.

This suggests an inquiry not only as to the relative carrying powers of springs of like material, but of square vs. round wire.

A comparison shows that a square wire will carry but 1.21 times as much as a round one, while the section is 1.28 times as great.

Mr. F. H. Richards.—The theory of spiral springs, I presume, is now pretty well understood, as a scientific matter relating to the torsion of the metal; but there are one or two facts that have been discovered practically in special machinery—manufacturers' machinery, particularly—that may be of quite as much interest.

Some twelve or fifteen years ago I had occasion to assist in de-

signing and building quite an extensive set of machinery in which spiral springs were an essential part, and in the investigations preparatory to the work it was found that it had been customary to use springs very much too small for the work. For instance, a mechanic, in building a machine, would put in a shaft, with perhaps a dozen cams on it. They were to him important pieces, and he made them large, with ample roll surfaces, and otherwise of good proportions. But the springs which produced the reverse movement were apparently neglected, or considered a small matter. Consequently there are frequent breakages. That has been the experience, I think, of nearly all mechanics using quick-running machinery having parts moved by springs. We found with springs of average material, such as could then be obtained in the open market, that if the spring were wound ten diameters of the wire and subjected to a motion not exceeding one-fifth of its length, it would be practically an enduring spring; and *vice versa*, if it was wound five diameters of the wire and subjected to a motion of more than one-tenth its length, it would not long endure the work. What I would call a good endurance for a spring, for such work, would be where one within those proportions makes, say, from sixty to a hundred strokes per minute ten hours a day 250 or 300 days in the year, and stands up to its work as a usual thing for two or three years.

In regard to the best way to put in a spring, I think that ninety-nine cases out of a hundred will require a pulling spring for endurance. A push spring, if a spiral of much length, it seems to me, is radically defective, both in theory and in practical work, because the spring, to do its work well and effectively, must have its axis in a straight line, and have it continue so, which with a push spring is practically impossible, for this reason: the wire, when wound spirally upon a core, fits the core, except a little expansion, of course, in unwinding; but when it is pushed together over the core it enlarges its diameter. This allows the axis to take a zigzag or curved course. Now this bending on the core produces a greater torsion at that part where the bending takes place, than the average torsion throughout the length of the wire, frequently straining it beyond endurance. Consequently, in several cases tempered steel springs have had to be abandoned after long trial. Sometimes, in order to secure endurance of the springs, and to get rid of the expense of constant renewals I have known machines to be re-designed and lengthened out to the extent of 30 or 40 per cent.

It is a matter of much importance in designing machines to provide room for springs of ample size.

I agree with the speaker that brass of proper temper, and well drawn, is the best material for ordinary springs for machinery. Next to that I think that mild steel well drawn will give the best satisfaction.

Mr. Smith.—Mr. Chairman, I would say to Mr. Richards that I have used a large number of push springs, necessarily; I could not use any other kind in certain kinds of machinery, and they do not work upon rods, but in holes. In that case we usually close the end of the spring in, conically, until the end coil is very small, or in some cases bend the end of the wire across, which, of course, gives the line of push in the axis, as it ought to be. In a case like that, where you can use a spring in a hole, it is all right; but a push spring upon a rod where you cannot do that is, I admit, defective in theory, as Mr. Richards says, although in practice we find many in use and get very good results. For instance, car springs, which are very short in proportion to their diameter, have just that defect. The pressure is brought to bear upon one side of the spring, and yet they seem to work well. Of course, the longer a spring is in proportion to the diameter, the less this evil comes in. I do not think the enlargement of a spring by compression, if the rod upon which it slides fits it properly, amounts to enough to be of serious import.

The matter of often-repeated use is a thing that probably has not been sufficiently investigated in regard to springs. I have made a few experiments with small springs, giving them about a million compressions, and although they were moved considerably within their elastic limits, they seemed, as a rule, to get shorter at the end of the millionth stroke. I did not, however, carry out the experiments far enough to obtain any reliable data upon the subject. The permanent set was partly owing to the spring wearing. It ran on a rod, and it wore a little upon the inside, which, of course, weakened it.

As to the principle governing the action of spiral springs, of course I did not claim that there was nothing at all published. I stated that I had failed to find it in looking over certain books I had at hand by Rankine, Clark and others. I believe that in some of Rankine's works the whole thing is treated, though I did not happen to have access to it when writing the paper. I only stated that this principle is not well known as a general thing, and

that all the spiral spring-makers to whom I wrote knew nothing about it whatever. In short, it has not become popular mechanical knowledge.

I have myself had similar experiences to those which Mr. Richards speaks of, in having to lengthen springs after they were first designed. I know a class of machines, built by manufacturers in New York State, certain springs on which were always "giving out," either breaking or setting so that they failed to do their work, and I know that a prejudice among buyers came up against that machinery built with those springs. The trouble came from the fact that they had not given length of spring enough for the amount of motion. And we found in a similar class of machines that we were building (although we put in much longer springs than the other parties) that the springs set. We nearly doubled the length, and they have ever since worked splendidly, and given no trouble whatever.

I want to ask Mr. Richards a question regarding those proportions he gave. You stated, sir, that where a spring was wound with a coil ten diameters of the wire, you could move it and allow its stroke to be one-fifth of its length. Now, did you mean its working stroke after it had been extended to the point where you start for the working stroke?

Mr. Richards.—I referred to the working stroke. The proportion of the extension was also determined approximately in these experiments, but I could not give the figures for that, but we did not use excessive extension as compared to the working length.

Mr. Smith.—Of course, for any *rule* in the matter it would be necessary to know first the extension, and after that the stroke out to the longest working point.

Mr. Richards.—My impression is that the total extension of the spring was one-fourth or one-third of its length; the spring was a pulling one, push springs not being used.

Prof. Webb.—I would like to state as to the treatment in Rankine, that it covers half a page, I think, but in Weisbach all kinds of springs are fully treated.

With reference to the proportions given by Mr. Richards, I understood that a spring wound upon a core with a diameter equal to ten times its own diameter—that was the proportion, I think—could be compressed one-fifth of its length without taking a set. Now, if I understand rightly, that does not allow for the number of

turns in the spring, which would seem to me to make an important difference. That is, a spring ten inches long might have ten turns in it, and it might have twenty. In one case it would have double the length of wire that it would in the other, and consequently it would have double the amount of compression.

Mr. Richards.—I did not mention that, for the reason we always in our practice wound the spring solid, the coils close to each other, for we had abandoned in our general practice the use of push springs on account of their unreliability. In some classes of machines great numbers of springs are used, and I know of one instance where about two hundred machines of one kind are running in this country, with probably twelve to fifteen springs each, of about the proportions I have stated, and the springs last for many years.

Mr. Woodbury.—Mr. President, those who desire to look up the formulæ relative to springs will find the subject of both spiral and coil springs treated more fully in "Der Constructeur" by Reuleaux, than in Weisbach or Rankine.

Mr. Grant.—In the works of the Pratt & Whitney Co., there are five automatic tap thread machines running. They have springs that run on a rod—push springs. The springs are wound open, and are about a tenth of an inch in diameter; that is, the spring wire is about a tenth of an inch in diameter, and they are wound open a trifle more than the diameter of the wire, and are not over six diameters in size. Those springs are compressed to less than half their length; and they have been running to my knowledge, five years, making perhaps twenty strokes a minute, and they are just as good as they ever were, for all I know.

Mr. Richards.—I would like to ask Mr. Grant how large a number of those springs were in use, so as to get some data as to the percentage, or value of the test in that case.

Mr. Grant.—There were five machines running and they had two springs—ten springs. I think it makes a great difference in the way the springs are tempered.

Mr. Smith.—Speaking of temper, I would just say, that tempered steel of proper quality is, I believe, the most elastic metal in existence; and springs of that kind would stand a great deal more compression, relatively to their diameter and the diameter of the coils, than brass springs would; but I believe that brass springs are cheaper and more reliable where you can get room for plenty of length and plenty of diameter in proportion to the stroke, so as not to

bring them down to the elastic limit. No doubt the springs Mr. Grant speaks of, if they were made of brass, would have set long ago; but if there had been room for them the brass would probably have been as good or better. In any case where I speak of brass being better, I mean on account of its freedom from temper-cracks and extra brittle spots, which cannot always be discovered during inspection, and may cause breakage at some unexpected time—perhaps after long use.

Mr. Capen.—I would ask Mr. Grant to repeat what he said as to the amount that the spring was open after being closed. I did not quite get it.

Mr. Grant.—The distance between the coils when open was about once and a half the diameter of the wire. The springs were compressed to less than half their length. That was all the room we could possibly get in the spaces the springs were in.

The President.—If there is no further discussion on this subject, the Chair would remark, that having occasion some time since to design some springs for pump valves which necessarily must be brass springs on account of working in water, he investigated all the formulæ that we could find—those of Rankine, Weisbach and Reuleaux—and springs were constructed and tried. Finally a formula which was given me by Mr. Atterburg, one of my draughtsmen (taken from a German text book, I think), came nearer than any other, and was quite accurate. These springs were quite light. They were push springs. They were one and one-half inches in diameter, made of wire a little less than an eighth of an inch in diameter, and were some three inches long. The lift of the valve was about six-tenths of an inch. The extreme pressure on the spring was not, I think, over six pounds. We found that Mr. Atterburg's formula was nearer than any other. I will try in printing the remarks on this subject to give that formula. I do not remember the name of the work, as I do not read German. But it will be interesting, perhaps, to the society to know that Mr. Corliss in his pumping engines uses a spring made of phosphor bronze about one thirty-second of an inch thick and some quarter of an inch wide, the object of this spring—it is a push spring,—being to keep the valve from lateral movement. The idea is that in case any foreign object should get under the seat the valve would come down over the spot until the next stroke, when the piece would be washed out without causing the valve to leave its line of movement. The springs and valves are of the same diameter, about two inches and a half

at the base. The upper diameter of spring is possibly an inch and a half, and the whole height of the spring is some inch and a half. I do not know the endurance of those springs, but I should suppose that in one of the engines mentioned there were from forty to fifty revolutions made per minute, and that probably a set of springs will last a year. You can readily see with an engine running twelve hours a day how many compressions the spring is subjected to.

Mr. Grant.—Mr. Pickering has had a push spring in operation. He might give us his experience.

Mr. Pickering.—I beg pardon, it was a torsional spring.

The President.—I think we shall all admit that this is a very important subject, springs being an essential feature in mechanical construction, and if any member who has information on the subject will print the remarks which he might wish to make as to his views on this subject, it will be a valuable contribution to the subject.

THE BOWER-BARFF RUSTLESS IRON PROCESS.

BY

GEORGE W. MAYNARD, OF NEW YORK.

The substitution of costly and not easily oxidized metals for iron in structural, engineering and art work has been rendered necessary because of the difficulty which has always been experienced in so protecting the surfaces of cast or wrought iron as to prevent the corrosive action of the atmosphere or water. The multitudinous devices in the form of paints, coating by immersion in molten metals (galvanizing and tinning), or the electrolytic deposition of metals have at the best been very unsatisfactory expedients.

With the exception of the noble metals, iron far exceeds all others in the ease with which it can be manipulated and converted into artistic forms, as is shown in the beautiful hammer work of Germany and Belgium, and the fine castings of Ilsenburg and Coalbrookdale in Europe, and Poulson and Eger, the Magee Furnace Co., the Yale Lock Manufacturing Co., and others in this country. But rust has come in to spoil many a beautiful work of art, notwithstanding the veneer of copper, brass and nickel, so that it began to look as though iron was doomed except for such constructive work as would be hidden by brick and mortar. It is well known that the architect shuns the use of iron where it comes in contact with stone, owing to the unsightly streaks of rust which speedily deface the surfaces of both the iron and stone. Any device which will absolutely prevent rust, without marring the beauty of the iron must be hailed with delight by the architect, manufacturer and engineer. The coating must admit of easy application, must be pleasing to the eye, must be susceptible of taking and holding paint—where, for any reason paint becomes necessary—must not injure the iron, and must be cheaply and quickly applied.

These requirements are complied with in a marked degree by the Bower-Barff Process.

The process has been so long before the public and has been so fully described in the able papers of Mr. George Bower, read before the Iron and Steel Institute of Great Britain in 1881, and before the Society of Engineers in London last month, and by his son, Mr. A. S. Bower, before the American Institute of Mining

Engineers in February last in Boston, that much which I have to say will of necessity be extracted from these papers because they cannot well be improved upon. I here make a general acknowledgment of my obligation to these gentlemen.

In 1876 Prof. Barff read a paper describing his process before the Society of Arts in London, which created a great deal of interest at that time.

The Barff process consists in placing the objects of iron or steel into an iron muffle, which is heated by the external application of heat, and then, when at a sufficiently elevated temperature, depending upon the nature of the articles to be operated upon—whether cast or wrought iron, heavy or light—steam superheated up to about 1,000° Fahr. is turned into the muffle, and the formation of magnetic oxide immediately commences. The heated iron or steel decomposes the steam, taking up certain definite proportions of oxygen forming Fe_3O_4 or magnetic oxide. The thickness of the coating depends upon the duration of the operation, and the time varies from six to eighteen hours. Magnetic oxide so formed is in its substance black, but when the articles first come out of the muffle they have a bloom on them very much like that upon a ripe damson.

The Barff process, as it was carried on by the professor, was necessarily an expensive one, because there was required first the steam, then the superheating of it, and the external heating of an iron muffle, which had not a very long life. Wrought requires less heat than cast iron, so that a muffle lasts much longer for wrought alone than if it has to be used for both. A good deal of beautiful work was done during the three or four years the process was worked by the professor, but it was not taken up by the iron trade, on account of its cost.

At one time it looked as though what had promised so well was to turn out commercially unsuccessful or at best to have but a very limited application.

The ingenuity and perseverance of the Bowers, father and son, came to the rescue, and as a result we have the triumph of to-day as is shown in the samples exhibited.

Mr. A. S. Bower in his Boston paper gives a very interesting account of the many difficulties with which he had to contend before arriving at satisfactory results, and then proceeds to give an account of the present method of treatment and the chemistry of the process.

There was commenced a series of experiments with carbonic acid chemically produced by the decomposition of chalk, the idea being that three equivalents of iron would unite with four of carbonic acid, forming one equivalent of magnetic oxide and four of

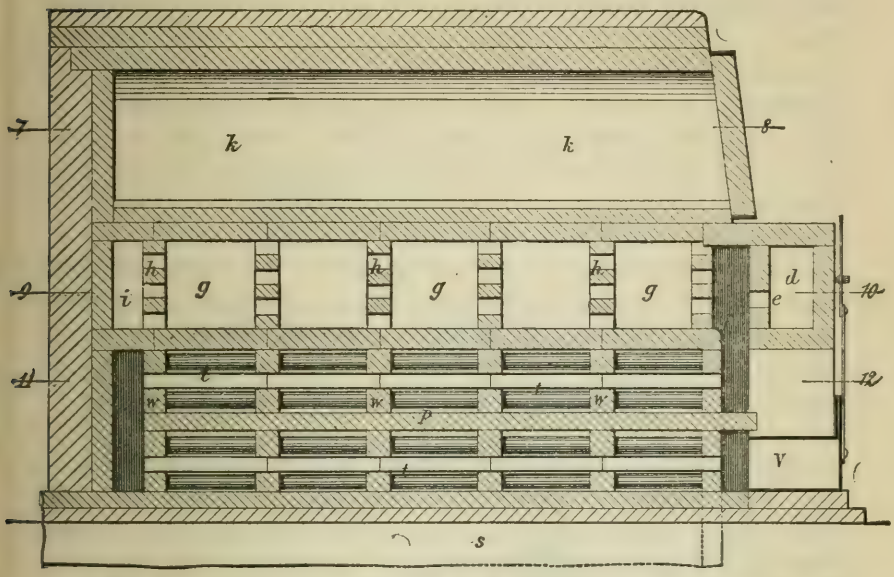


FIG. 1.—LONGITUDINAL SECTION OF BOWER FURNACE ALONG LINE 1—2 IN FIG. 3.

carbonic oxide, if the heat were sufficiently high. This reaction is expressed symbolically thus: (1) $3\,Fe + 4\,(CO_2) = Fe_3O_4 + 4\,(CO)$. This is the simplest action that could take place, but it was evident from the results that something quite different was obtained, inasmuch as the coating was very light in color, pleasing to the eye, but easily removed, and in that sense entirely differing from the articles you see before you. This coating, from effects exactly similar and designedly produced by a studied manipulation in the furnaces in successful operation in England, France and here, proves pretty conclusively that carbonic acid, practically pure, produces upon iron, at an elevated temperature, a film which is, in composition, a mixture of *Fe O* and Fe_3O_4, or, at all events, it is nearer the metallic state than is magnetic oxide. But even supposing that the results obtained by the carbonic acid had been successful as then carried out, the objections referred to concerning the air process would still exist, as external heat and a closed iron

muffle would always be necessary. I therefore proposed to use a fuel-gas producer, similar in principle to the Siemens' generator, but altered practically to suit other requirements, to burn the combustible gases thus produced with a slight excess of air over and above that actually required for perfect combustion, and to heat and oxidize the iron articles, placed in a suitable brick chamber, by these products of combustion. I also arranged a continuous regenerator of fire-clay tubes underneath the furnace, so that the products of combustion leaving the oxidizing chamber passed outside the tubes, imparting a portion of the waste heat to them, which was taken up by the in-going cold air passing through their interior on its way to the combustion chamber. I had hoped in this way to be able so to regulate the excess of air over that required for complete combustion as to be able to produce magnetic oxide directly, instead of the lower and useless oxide or combination of oxides produced by carbonic acid alone. I obtained some beautiful results, and some again were unaccountably bad, and I soon found that it was as difficult to regulate the precise amount of oxidation as it was first in the Bessemer process, and I was fortunate enough to hit upon an almost parallel remedy—that is to say, I increased the quantity of free oxygen mixed with the products of combustion, and oxidized the iron articles to excess during a fixed period of generally 40 minutes, when magnetic oxide was formed close to the iron and sesquioxide over all. Then for 20 minutes I closed the air inlet entirely, leaving the gas-valve open, and so reduced the outside coating of sesquioxide to magnetic oxide by the reducing action of the combustible gases alone.

The excess of oxygen in the first instance produces Fe_2O_3, or sesquioxide of iron, and the under surface of this, being in contact with metallic iron, undergoes reduction to magnetic oxide in the following manner: Four equivalents of sesquioxide unite with one of metallic iron, forming three equivalents of magnetic oxide, or, symbolically (2) $4(Fe_2O_3) + Fe = 3(Fe_3O_4)$.

When deoxidizing by combustible gases, consisting mainly of carbonic oxide, three equivalents of sesquioxide unite with one of carbonic oxide and form two equivalents of magnetic oxide and one of carbonic acid, and, symbolically (3) $3Fe_2O_3) + CO = 2(Fe_3O_4 + CO_2)$. Another method of reduction is by carbon itself, when the formula stands thus: (4) $3Fe_2O_3 + C = 2(Fe_3O_4) + CO$.

Formula (3) is also the reaction when rusty iron is reduced by producer gases, and which consist largely of carbonic oxide, and by

the specimens exhibited it will be seen that articles completely pitted with rust may have their surfaces rendered rustless. In this case the periods of oxidizing and deoxidizing are reversed—that is to say, the latter occupies 40 and the former 20 minutes. No oxidizing is theoretically necessary, but practically a certain amount is requisite to keep up the heat in the chamber, which, of course

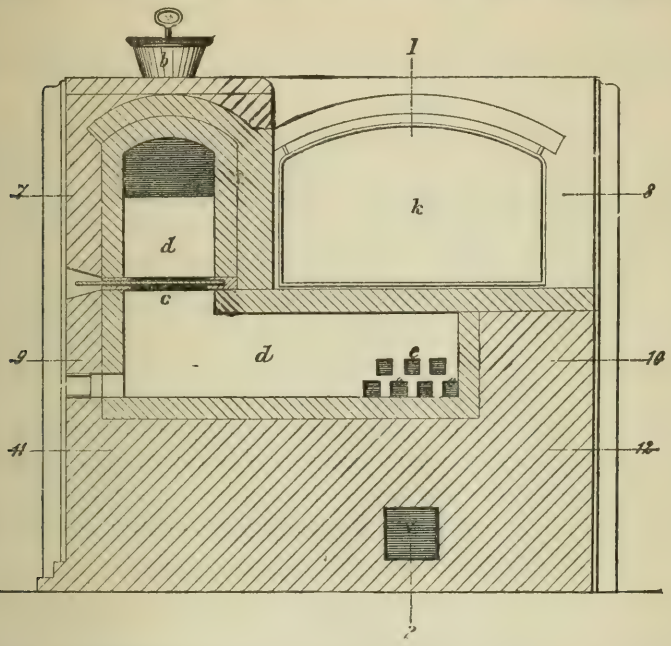


FIG. 2.—TRANSVERSE VERTICAL SECTION ALONG LINE 3—4 IN FIG. 3.

could not be done unless combustion took place some time or other. I only mention the reduction by carbon as exemplified by Formula No. 4 because, while experimenting with a furnace, I was asked by the proprietors of a valuable red-oxide deposit, which was found in so finely divided a state as to be capable of being used at once as a paint, whether I could reduce it to a magnetic oxide. I tried to do so by carbonic oxide, but I found that only the surface of it was affected, and that even this, when taken out of the furnace, speedily returned to its original red color by the combined actions of the hot unconverted material underneath and the air above. It will be found from formula (4) that $2\frac{1}{2}$ pounds of carbon are required to reduce 100 pounds of red oxide. This I mixed intimately, in the shape of powder, with the red oxide, brought the mixture to a red heat and

the result was black magnetic oxide. Not only this, but by adding more carbon I could make the color lighter and lighter until it was almost identical with the coating produced in my previous experiments with carbonic acid, and by reducing the quantity of carbon below 2½ per cent., various shades of purple were obtained, the red appearing more and more prominent as the quantity of carbon was diminished.

OBSERVATIONS AND IMPROVEMENTS MADE IN THE AMERICAN PRACTICE.

1. In England a non-coking gas coal is employed, and the producers of the first furnace erected in this country were proportioned for this variety of coal. Considerable difficulty was experienced at first, and not until a West Virginian splint was tried were satisfactory results obtained. The high price of this coal in New York proved a serious drawback to its continuous use. Mr. Bower and Mr. Winslow, of the Hecla Works, hit upon the happy expedient of substituting anthracite and petroleum for the bituminous coal. Petroleum is allowed to trickle through a small pipe at the rate of about one gallon per hour upon the red hot surface of the coal in one of the gas producers. It is especially advantageous, because just at the right period it furnishes a large volume of reducing gas. The petroleum is greatly superior to any coal, because it is under such perfect control.

2. Sawdust, together with anthracite, has been very successfully employed when it was necessary to raise the temperatures of the furnace in a very short time. As the combustion is absolutely controlled by proper valves, *three bushels* of pitch pine sawdust have been gradually consumed during 1½ hours.

(3) The most important improvement made in this country is the use of superheated steam in the Bower Furnace in finishing the treatment of castings. Heretofore such treatment has consisted in successive oxidations and reductions. It is found that after the last reduction the admission of superheated steam for a period of 1–2 hours is very advantageous. It re-oxidizes any over-reduced coating and insures a coating of constant quality, besides imparting a fine luster to the coating and noticeably increasing its tenacity. This improvement was made by Mr. Bower before his return to England.

(4) A low temperature, not above incipient red, is required in obtaining good results with polished work, wrought or cast. Con-

tinental practice is reported to have shown that the treatment of iron with steam superheated to a higher degree than the temperature of the articles themselves produced the best results. The same has been found the case in this country. A charge of polished ware is run into the furnace which is at a certain temperature—say red heat—and the metal soon absorbs the heat and reduces the temperature. The combustion chamber and regenerator, however, hold their higher temperature and effectively superheat the steam before it reaches the iron in the furnace chamber. By simple trials the quantity of heat absorbed by a given charge of iron can be ascertained, and thus a practical means is afforded for guidance as to the temperature to which the furnace must be raised before introducing the charge. By this practice the cost and other disadvantages of an externally heated muffle are obviated, while treatment in the direct Bower Furnace can be carried out without heating the charge by burning gases. This is considered an important advance in obtaining good results with polished articles, for the producer gases, especially those from hot anthracite fires, are apt to have a cutting or roughening effect on fine ware. Polished work treated in this improved manner, and then rubbed up with flour-emery and oil, has a tenacious coating of a remarkably brilliant blue-black luster. Such treatment, however, is not required on ordinary iron for which the operation is accordingly carried on at higher temperature and in relatively shorter time.

(5) Articles which are to be exposed to active rusting influences are treated for 7–9 hours, while such as are intended for indoor exposure receive but a very thin coating in an operation which lasts from 2–4 hours. Such articles, subsequently polished, cannot be guaranteed against prolonged outdoor atmospheric influences. Minute particles of the *thin* coating are apt to be removed in the polishing process, exposing the metallic surface to oxidation. The treatment in the case referred to is rather for the purpose of ornament than for very thorough protection.

(6) Foundry sand, if left on the castings, is not in itself injurious, since the magnetic coating forms beneath it. It has, however, a red, rust-like appearance after the treatment, and this impairs, for many purposes, the market value of the articles. A very simple, cheap and effective means of removing the most firmly adherent sand, especially in castings having an irregular surface, is a steam sand blast, or, better still, a steam and water sand blast in a small apparatus having the form of an injector which drives a jet of hot

water and sand against the casting. This contrivance, as well as the other improvements here mentioned, are due to the able and active interest of Mr. Winslow, of the Hecla Iron Works of Brooklyn.

(7) The temperature for treating ordinary rough cast and wrought iron being a good red, precaution must be taken to support the articles with some degree of uniformity in order to guard against distortion. No difficulty has been encountered on this score. Very thin iron, such as sheets, is preferably treated at a dull red; there

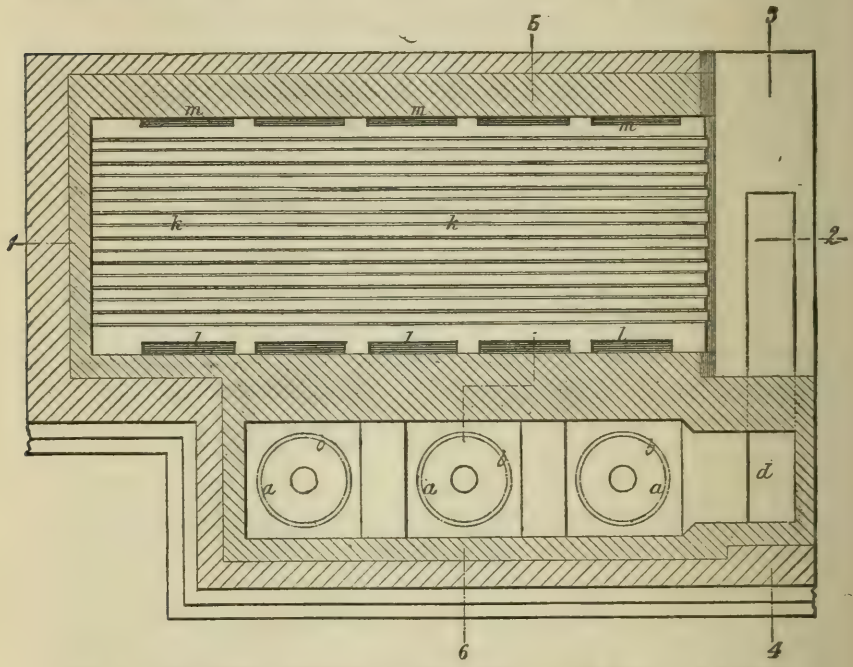


FIG. 3.—HORIZONTAL SECTION ALONG LINE 7—8 IN FIGS. 1, 2 AND 5.

is then no chance of buckling or bending, even without much supporting. As a rule it is not found desirable to treat in one charge both very light and very heavy articles. The former become overheated and distorted at a temperature which is just right for the latter. For many articles the temperature can without injury be raised sufficiently high firmly to bind two pieces of iron by means of the oxide as cement. This welding property promises to open a wide field of utility in treating sheet iron pipe, cans, etc., which require water-tight joints.

(8) If it is desired to treat at one and the same time both polished

and ordinary ware, a wash of plaster of Paris, applied to the polished surfaces, prevents the cutting or roughening action of the hot gases upon them.

(9) Plaster of Paris is also used, in moderately thick coating, to protect the screw threads of bolts, gas pipe, etc., from an energetic oxidizing action. A thin, but perfect coating is formed beneath the plaster—ample to protect the threads until they are finally screwed up—while not thick enough to create difficulty in fitting or to require a special threading in ordinary architectural or stove work—cases in which screws and nuts always have a certain amount of play. For small bolts and nuts, closely cut, is has sometimes been found advisable, though not absolutely necessary, to cut the nuts with a taper tap. In more accurate machine work the proper bolt holes are drilled before the oxidation. Subsequently each hole is reamed out (by which the coating is removed) and the thread accurately cut. The screw joint must be protected from rust by oil in the usual way.

The following extracts are taken from an article which appeared in the *Revue Universelle*, published in Belgium.

After describing the furnaces and chemistry of the process, the writer says:

The rustless articles withstand the effects of heat, while coverings of paint, galvanizing, tin and enamel suffer very much under its action. A piece of rustless iron can be heated to redness, and then plunged into cold water without the least scaling or other change, so slight is the difference between the coefficients of expansion of the magnetic oxide and the metal.

Rustless iron is not affected by fresh water holding air in solution, nor by brines or alkaline solutions or sulphureted gases, and it withstands the action of salts in general, especially sulphate of copper.

Coated articles may therefore be exposed to sea water or to the most varied atmospheric conditions. Cast-iron receivers used for six months as urinals remained perfectly free from corrosion, while similar receptacles not protected by the oxide were strongly attacked.

Van Aubel, engineer of the Maestricht Royal Paper Factory, treated several articles, and then exposed them to the fumes of the laboratory without any deterioration.

Flamache, engineer of the Belgian State Railways, makes the following statements in a report on the Bower process:

1. Hydrochloric acid diluted to $\frac{1}{10}$ converts the magnetic oxide into sesquioxide which it dissolves, and into hydrated sesquioxide which scales off the surface, exposing the metal to the direct action of the acid.

2. A solution of caustic soda has no effect on the coating. If there is a crack in the coating, the exposed metal will rust as usual, but the rust will remain localized.

Though the adhesion of the Bower-Barff coating is considerable, it is not sufficient to permit of working and fitting iron in the same way as material that has not been treated. Rustless nails can be driven into wood and then withdrawn without injury to the coating. Coatings can be drilled without injuring the coating on the rim of the holes.

Flamache claims to have obtained the following results:

1. The rustless treatment does not alter the strength of the iron.

2. Under tensile or compressive strains the oxide adheres firmly to the iron until the limit of elasticity of the metal has been reached.

3. The oxide is chipped off the metal by a blow of the hammer; in riveting the coating to a distance of one centimetre around the rivet head scales off; and in shearing the coating scales along the edge of the metal.

According to these tests iron can be protected from rust when the articles are not to be submitted to subsequent mechanical treatment.

The magnetic coating can be reduced in thickness to a mere film, which will protect fine castings and polished ware from any but very energetic rusting action, producing at the same time a very artistic effect.

The first articles treated at the Hecla Works were suspended from the ceiling of the plating room, where they have been exposed above the vats to warm steam and acid fumes since the 20th

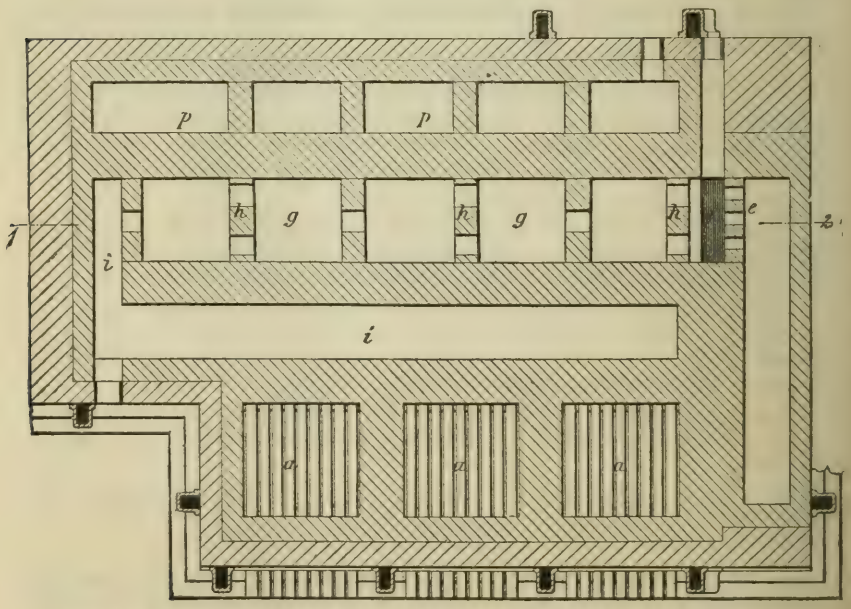


FIG. 4.—HORIZONTAL SECTION ALONG LINE 9—10 IN FIGS. 1, 2 AND 5.

of January last. They are absolutely unattacked, while plated and galvanized articles hung up at the same time were speedily red

with rust. Articles hung in the exhaust steam in the foundry yards were also unaffected.

I am indebted to my assistant, Mr. W. B. Kunhardt, for certain suggested improvements and for careful noting of results.

These improvements will be applied to furnaces now being constructed, and will also result in a considerable reduction in cost.

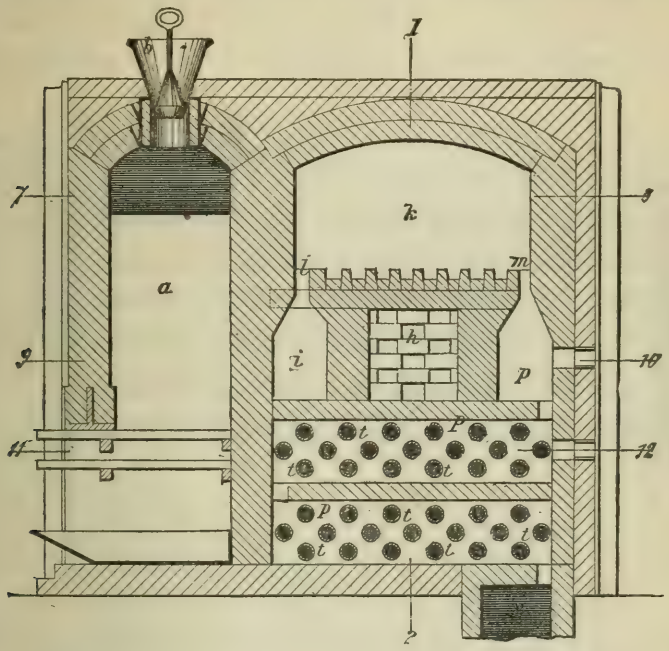


FIG. 5.—TRANSVERSE VERTICAL SECTION ALONG LINE 5—6 IN FIG. 3.

The accompanying cuts represent the English type of furnace which has been in continuous use for six months at the Hecla Iron Works in Brooklyn.

"The furnace is so constructed that the carbonic oxide from the generator being caused to meet with a current of hot air, combustion takes place, which is perfected before the products therefrom are admitted to the chamber containing the articles to be coated, and the waste products of combustion are caused to pass on their way to the chimney over and among a series of pipes, through which the cold air required for combustion is admitted, so as to become heated and prepared for admixture with the carbonic oxide. Continuous regeneration, therefore, takes place, and the operations are effectively performed under the most economical conditions.

In the following description the same letters of reference indicate corresponding parts in all the figures:

"Fig. 1 represents a longitudinal section of the furnace, taken along the line 1—2 in Figs. 2, 3, 4 and 6. Figs. 2 and 5 are transverse vertical sections of the same, taken respectively along the lines 3—4 and 5—6, Fig. 3; and Figs. 3, 4 and 6 are horizontal sections taken respectively along the lines 7—8, 9—10 and 11—12. Figs. 1, 2 and 5, *a a a*, are the producers for gasifying the fuel which is supplied through hoppers *b b b*. The carbonic oxide

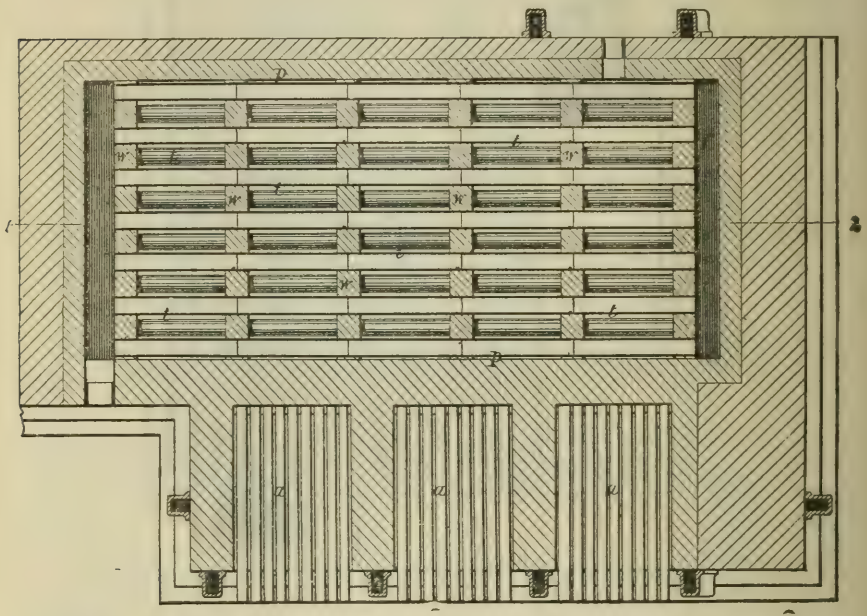


Fig. 6.—Horizontal Section along Line 11—12 in Figs. 1, 2 and 5.

from the combustion of the fuel in the producers *a a a* passes along a conduit, *d* (its flow being controlled by a slide, *c*), to the openings *e*, where this combustible gas meets a current of hot air ascending through a passage, *f*, and is consumed. The products of combustion are thence conducted along a passage, *g*, where they are thoroughly mixed by open brick-work cross walls, *h*, and then return along a passage, *i*, whence they enter, through the oblong holes *l*, the chamber *k*, in which the articles to be coated are arranged. After having passed over and among the articles to be coated, the waste escapes downward through ports *m*, into regenerator chambers *p*, and thence to the chimney flue *S*, heating in its passage the tubes

t composing the regenerator, and which are securely supported by the cross walls *W*. Cold air enters the apparatus at *v*, through a channel provided with a regulating valve under the control of the furnace tender. This air then passes along the lower rows of regenerator tubes and back through the upper tubes, thus becoming highly heated by the waste gases, and capable of developing greater heat when burned with the combustible gas."

DISCUSSION.

Mr. Henning.—What kind of fuel can you use to oxydize the material, or rather will large quantities of sulphur in the coal be injurious?

Mr. Maynard.—I am not able to answer that positively. I should assume, though, that it would be better not to have sulphur in the coal.

Mr. Henning.—I mention this particularly because in annealing steel bars we get as much as a sixteenth of an inch coating of sulphur on the bars, they being exposed about 30 hours to the gases coming up from the furnace from certain kinds of Pittsburgh coal, and I, of course, think that a very important matter in regard to this process.

Mr. Maynard.—I should presume it would be better to have coal free from sulphur; of course, we have not tested sulphury coal.

Mr. Oberlin Smith.—I would like to inquire the average thickness of the coating, and the maximum and minimum thickness of the coating in the various kinds of work on wrought and cast iron.

Mr. Maynard.—You can ascertain that by breaking off some of the coating here. If the things to be treated are to be exposed to any violent action, of course they want to be more thickly coated. I may as well say that with the exception of these polished samples, all of these samples have been lying in water a long time before they were brought here, and were then allowed to dry and were then wet again.

Mr. Le Van.—Why would it not be a good plan to coat boiler tubes by this process to prevent scaling?

Mr. Maynard.—We hope to have an opportunity of doing that, very soon.

Mr. Le Van.—For water tube boilers, that would be a great improvement, I should say.

Mr. Partridge.—Mr. President, in the paper which was read there was one statement made in regard to the endurance of this coating which, to those who are familiar with plumbing work, is more satisfactory and entirely conclusive than any other thing that could possibly have been suggested as a test. As I understood the statement, it was to the effect that a urinal had been coated by the process and been in constant use for six months without showing rust. Of all serious tests for rusting of cast iron or wrought iron, the urinal is the worst. No amount of painting, galvanizing lead-coating or enameling will protect an iron urinal. The acid seems to have a more destructive action on the iron than any other that iron is likely to come in contact with. And I should say that that was sufficient—if the coating will stand that, it will stand anything that it is likely to have elsewhere in the arts.

The President.—The chair would like to ask a question of Mr. Maynard: Have any tests been made concerning the use of this process for feed pipes, to overcome the destructive action of water of a certain temperature, which generally destroys wrought iron pipes especially?

Mr. Maynard.—No, sir; but we hope soon to have the pleasure of treating some pipes for our President, who wrote to me the other day on the subject. The difficulty was that our furnace was not long enough, but we are now putting up a larger furnace for the American Ship Building Company, so that we shall be able to treat pipes 22 feet long. Our policy has been up to the present time when inquiries have been sent to us, to have people send samples on, and let us treat them. There are lots of things we don't know about yet ourselves, and we should be very happy to treat anything, and then have it put to the most severe tests.

Mr. Hand.—I would like to ask if this process would not be valuable to treat the water end of pumps in coal mines? We had a statement last night of how destructive the acids contained in the water of coal mines is to the water cylinders of pumps.

The President.—I think Mr. Hand's question is a very pertinent one.

Mr. Maynard.—My answer is, that I should be very glad indeed to have it tested. Send us a pump and we will make the experiment. (Laughter).

Mr. Weston.—Did I understand that the coating would withstand the action of sulphate of copper?

Mr. Maynard.—Yes, sir.

Mr. Weston.—For any length of time?

Mr. Maynard.—These experiments that I have quoted are my authority. I have not yet had the opportunity of personally going into the matter in the detail that I would like.

Mr. Weston.—If it will withstand the action of sulphate of copper, of course it will stand the action of pretty strong sulphuric acid, because it will form a galvanic element there which would rapidly destroy the iron, and therefore I think it would meet the requirements of the gentleman behind who spoke about pumps, because in the mines you would have nothing to contend with but sulphuric acid; the other acids would not exist in the free state.

The President.—The Chair will remark in regard to his own experience that he desired the tubes from Prof. Maynard for some large heaters which we have. They are placed in flues, and consist of nearly 100 copper tubes, I think, about 700 feet long and two inches internal diameter. They were connected together by return bends and the water was pumped through the whole length of the heater, remaining a certain number of minutes (20 minutes or more), and it resulted in a very decided saving of fuel. But unfortunately the brass tubes of which the heater was composed lasted about a year, and then the sulphur in the coal attacked the brass and pitted it. After running about that length of time, the tubes began to burst. New tubes were inserted, but the casualties were so frequent that the firemen were alarmed, and we had to abandon the heaters, because it was considered that life was endangered. And we have remained until this time waiting to get hold of some material. We knew if we put in iron tubes that the feed water would very rapidly destroy them from the inside. We had no fear from any action of gases. And so these heaters, which cost us some $2,000 apiece, and the cost of which we could save very nearly in a year, have been obliged to lie idle until this process is ready for our use.

Mr. Root.—Mr. Chairman, I think the only thing you will find that will stand the action of acids upon flues or tubes is cast-iron. I have had some experience in that respect, and with wrought iron, I have known them to eat out inside of a month by putting cold water in them, where the water was so cold as to produce a sweat on the outside of the pipe; but cast-iron pipes seem to last very well. Now, there have been a good many Green economizers put in; I don't remember having heard of much trouble

with them. In those the pipes were made entirely of cast-iron, and I don't know that any of them ever gave out, although I have not had much experience with them. But I think there is one thing very certain; that you will find cast-iron will last better as a flue heater than any other material you can get. If the water is cold that is pumped through pipe, it seems to condense the acids from the products of the combustion on the outside of the pipes which will dissolve wrought iron in a very short time.

REULEAUX'S KINEMATIC MODELS.

BY

PROF J. BURKITT WEBB, OF CORNELL UNIVERSITY, ITHACA, N. Y.

In this paper Professor Webb explained the improvements made by Professor Reuleaux in the science of mechanism, and illustrated his remarks by a selection of models, copied from the celebrated collection of the Royal Polytechnic School at Berlin, and borrowed from the cabinets of Cornell University for this purpose.

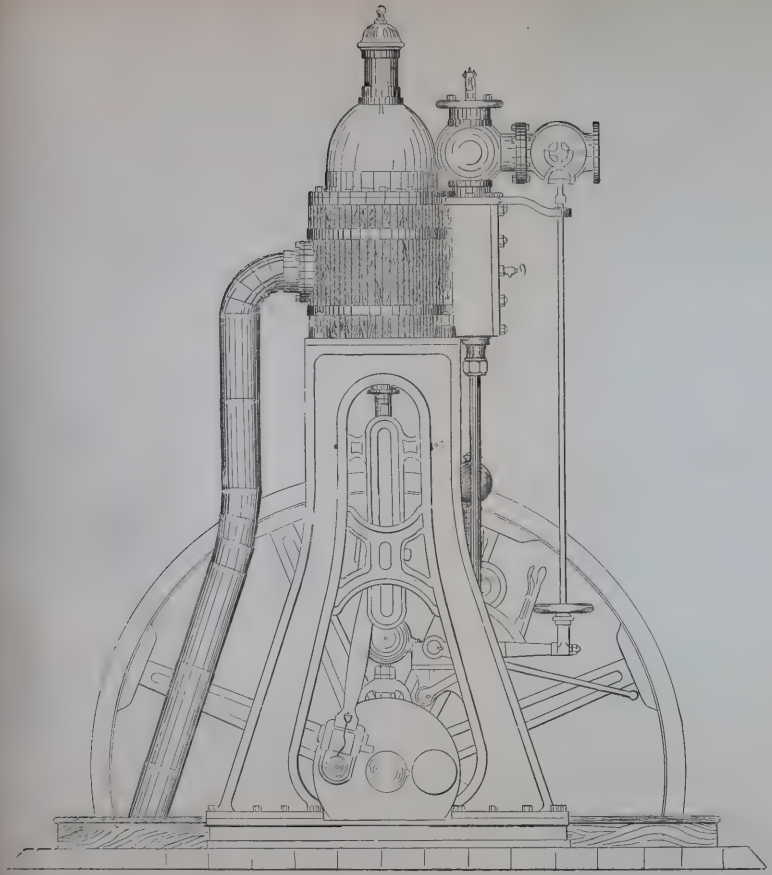
BALANCED VERTICAL ENGINES.

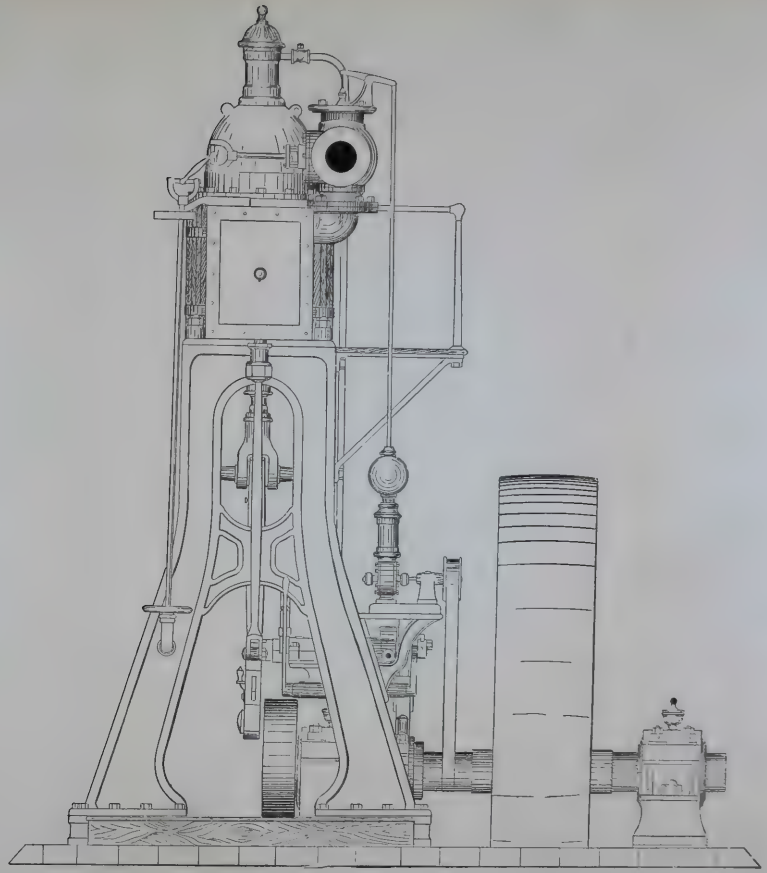
BY

W. F. DURFEE, BRIDGEPORT, CONN.

At the Altoona meeting of this Society, during the discussion of the paper of Prof. Robinson, there was a question asked relative to the possibility of balancing the moving parts of vertical direct acting engines, which failed to elicit a very satisfactory reply, the general impression being that it was a difficult problem, which might be, but never had been, satisfactorily solved by so arranging masses of metal that they moved in opposition to, and therefore balanced the reciprocating parts of the engine. It is the purpose of this paper to explain another method of balancing the reciprocating parts of direct acting vertical engines, for which the writer was granted Letters Patent, March 21, 1871, and which has been applied with success to engines designed by himself and others. The first engine to which the method of balancing about to be described was applied, was designed and erected by the writer in the years 1868–9, for driving a train of twelve-inch rolls in the works of the American Silver Steel Co., at Bridgeport, Conn., and I have selected the drawings of this engine to illustrate this paper, in which I will describe in addition to the peculiar method of balancing the moving parts, some other details of construction which I believe to be of value. The engine, as will be seen from the elevations, Fig. 1 and 2, is of the direct acting inverted cylinder type, and, in its general form and framework, presents no very conspicuous novelty, save that above the cylinder is seen what appears to be a dome surmounted by a cupola; to this feature I shall presently ask your more particular attention.

The diameter of cylinder and stroke of piston are each twenty (20) inches. The revolutions per minute when the train was run on small rods are two hundred and twenty-five (225), giving a piston speed of seven hundred and fifty (750) feet. The bed plate is six feet square and six inches in depth, and is strengthened by a number of ribs as shown in the drawing, Fig. 3. Before this plate is placed in position on the foundation it is turned on edge and filled with brick-work laid in cement mortar, and when this is suffi-





ciently dry to retain its place, the plate is turned down and leveled by a number of small pieces of iron in its final position, a space of

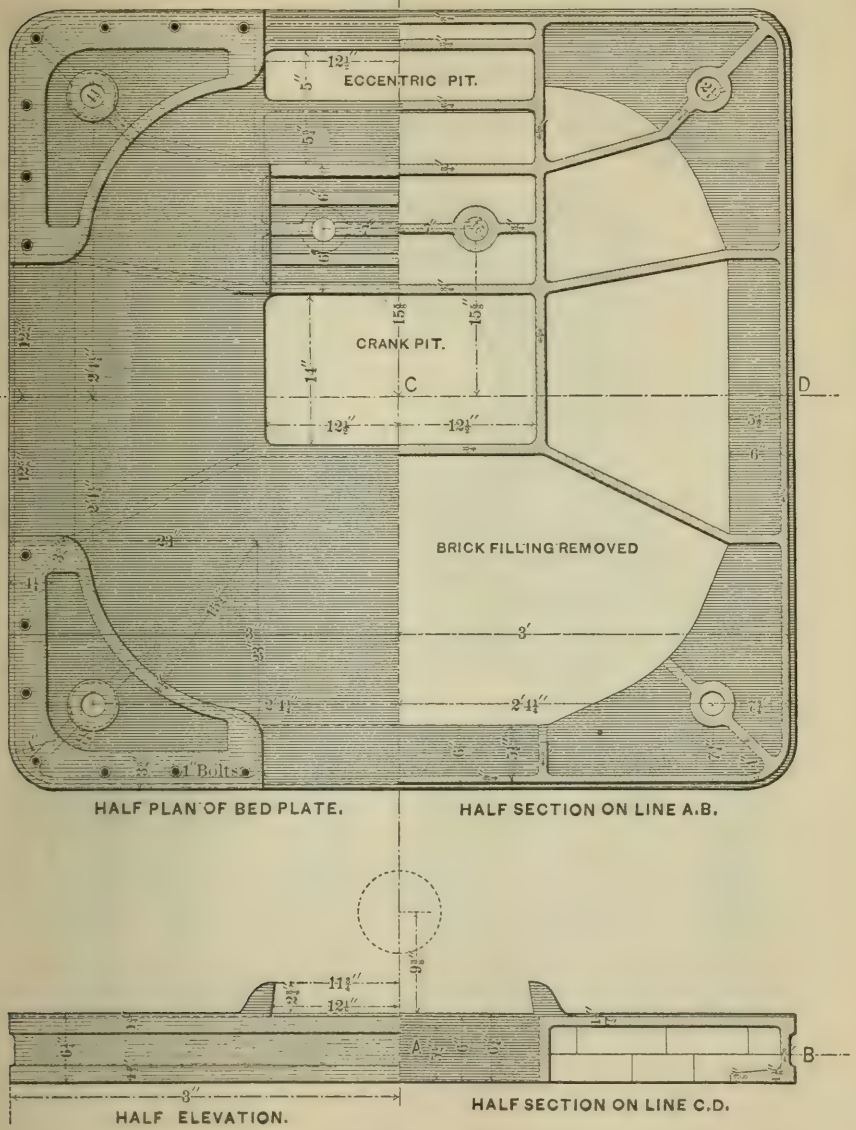


FIG. 3.

at least one-quarter of an inch being left between the under side of the brick-work in the bed-plate and the top of the foundation,

which space is run full of a strong cement grout as soon as the holding-down bolts are in place; thus insuring for the bed-plate a perfect bearing at every point of its area. The construction of the

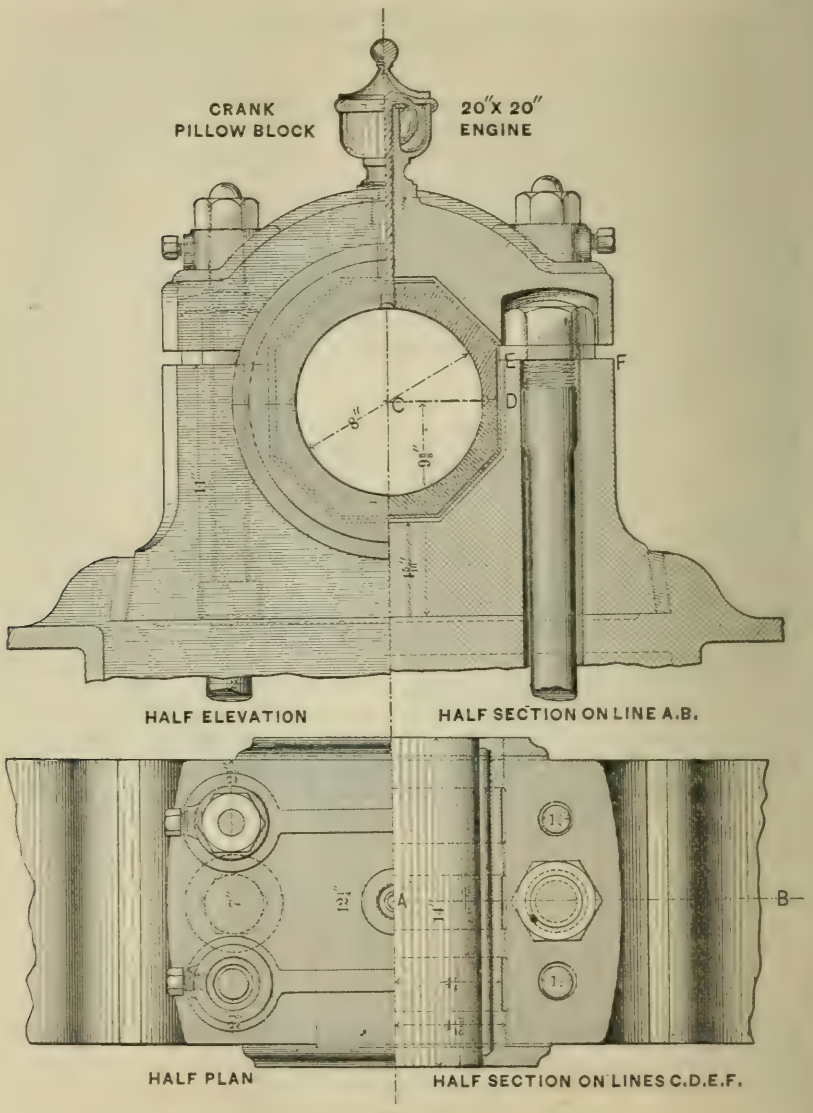


Fig. 4.

crank pillow-block presents some peculiarities; as will be seen in the drawing, Fig. 4, the pillow-block is held in position as against vertical displacement by two holding-down bolts, which pass

through its body in close proximity to the "brasses," the nuts of these bolts have a bearing upon the upper surface of the base of the pillow-block, and are covered by its cap; the block being secured against horizontal displacement by means of a key at each end. In this connection I will say that in some machinery which I have erected since the design of this engine, I have secured pillow-blocks against lateral displacement by running the space between the pillow-block and the key-lug full of Babbitt metal, and as the result of three years of experience of its use on a line of heavy shafting, I have no hesitation in recommending it as in every way satisfactory.

The frame of the engine has nothing especially novel in its details; it is composed of four similar castings fitted and bolted together, and provided with feet at their lower extremities, through which the holding-down bolts at the corners of the bed-plate pass, and they are also secured to the bed-plate independently of the holding-down bolts by a number of tap bolts, as will be seen in the elevations, Fig. 1 and 2. The four main castings of the frame are steadied and stiffened by four curved braces, which are fastened to them near the middle. The cross-head guides, which are simple rectangular troughs, in which the cross-head blocks slide, are secured to two of these braces as well as to the frame of the engine by turned and fitted bolts, the guides being planed in between vertical lugs on the inside of the braces, and all contact surface between guides and frame being also planed together.

To insure proper distance and parallelism between the under side of the feet and the top of the engine frame, after the frame and its braces were fitted together the whole was put in a lathe and the bottoms of the feet and the top of the frame were turned off. The steam cylinder is of the ordinary construction such as is in common use in the majority of tug engines; its bottom being cast solid with its body, save that a sufficient opening is left through its centre to accommodate the boring bar. This opening is closed by the stuffing box (figures 5 and 6), which presents one constructive feature which is believed to be novel, and which is certainly very satisfactory in its practical operation: I refer to the means by which the water which follows the piston rod through the stuffing box is trapped out and prevented from running over cross head and connecting rod. This is accomplished as follows: The stuffing box itself is made of greater length than usual and the packing is divided into two parts, separated by what may with propriety be

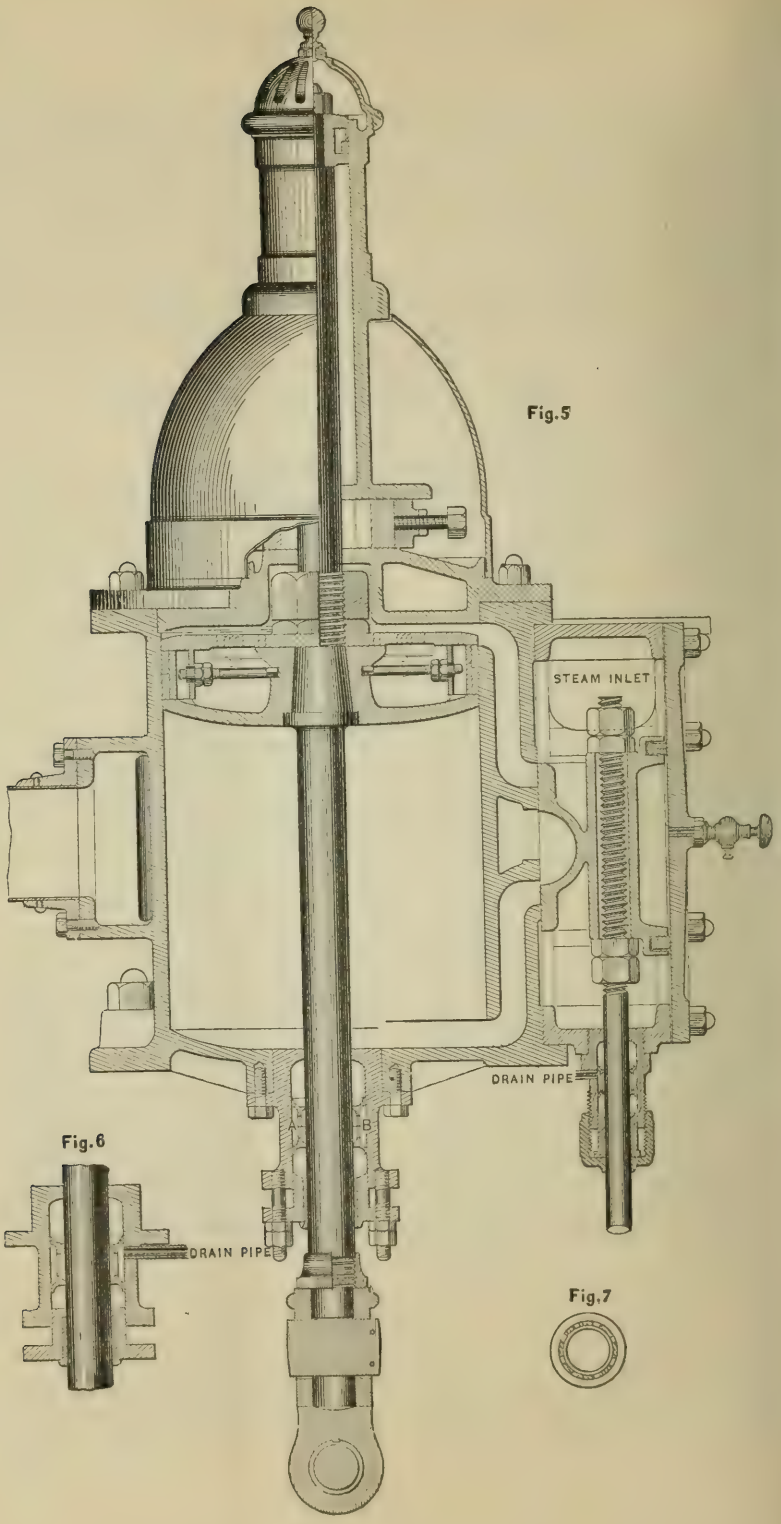


Fig.5

Fig.6

Fig.7

called a lantern gland, whose construction is plainly shown in the drawings, figures 5, 6, and 7. The larger part of the packing is placed above the lantern gland and the remainder below it, and the lantern gland, being free to slide along the rod as the gland proper is screwed up, communicates the pressure applied to the packing below it to the larger mass of packing above it. There is a drain pipe communicating with the hollow space of the lantern gland, for carrying off any water which is carried into it by the piston rod.

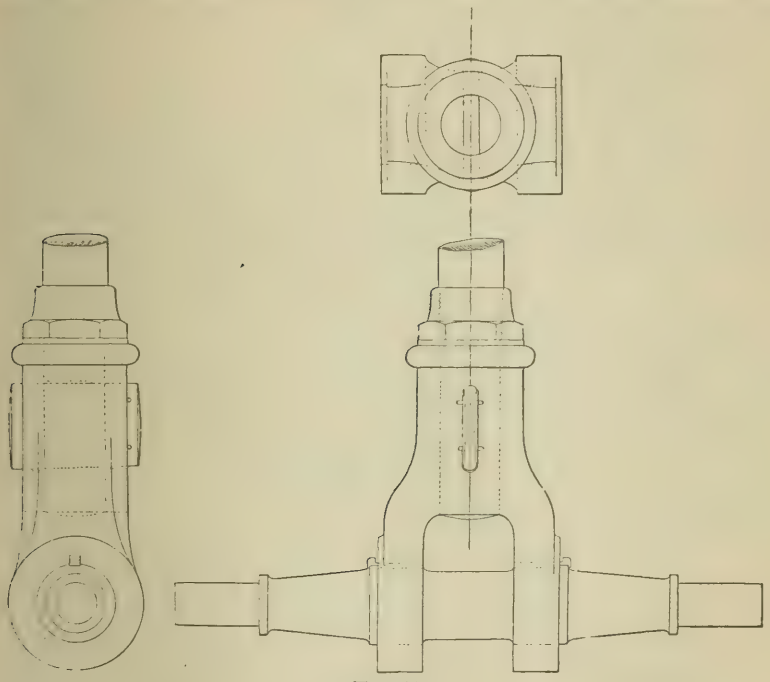


Fig. 13.

This drain pipe is so located relative to the lantern gland that, notwithstanding the latter's movement along the rod, it always remains in communication with the hollow spaces within it. The operation of this combination of parts is as follows: The water which follows the piston rod through the upper portion of the packing is received by the lantern gland from which the most of it passes off through the drain pipe, the portion of the water which is in that part of the lantern gland below the drain pipe being without pressure upon it does not find its way through the lower wart of the packing but remains in the gland and acts as a lubricant to the piston rod. The details of the cross head presents some constructive novelties; the

cross head block is a forked forging of wrought iron, which, instead of being bored "taper" for the reception of the conical end of the piston rod, is bored cylindrical, and the end of the rod is turned to fit it, and in order to preserve all the strength possible and provide a proper shoulder for the piston rod, a fine screw thread is cut upon it just above the cross head block on which is run a gun metal nut (as is shown in figure 5), which receives the downward thrust of the rod, its upward pull being sustained by a steel key passing through the cross head block and piston rod below the nut. This construction admits of a larger cross section of solid metal in the piston rod adjacent to the lower edge of the key than is usually given, and at the same time simplifies the workmanship required. The fork of the cross head block is bored at right angles to the piston rod, and through it is passed the cross head pin secured against rotation by two small keys: the extremities of this pin are turned cylindrical and are fitted, but not fastened, in cylindrical holes in the slide blocks; these are provided with "brasses," the working brass being adjusted for wear by a wedge bolt and nut, the wedge being pinched by a side set screw; both the working brass and its fellow are precisely alike, and when the working brass is nearly worn out it can be shifted to the other side of the slide block, a "liner" of proper thickness being made to take the place of that which secured the unworn brass in place: this "liner," as will be seen in the drawing, is planed into both the brass and the body of the slide block, and is prevented from dropping out by a small transverse pin, by removing which both liner and brass can readily be displaced without disturbing the body of the slide block, and the working brass can also be easily removed by unscrewing the adjusting nut on the wedge bolt and letting the wedge drop through the bottom of the brass. The lower ends of the "brasses" are provided with inclined holes, which, as these ends dip at every stroke of the engine into the oil cup at the bottom of the guides, carry up oil enough for their lubrication.

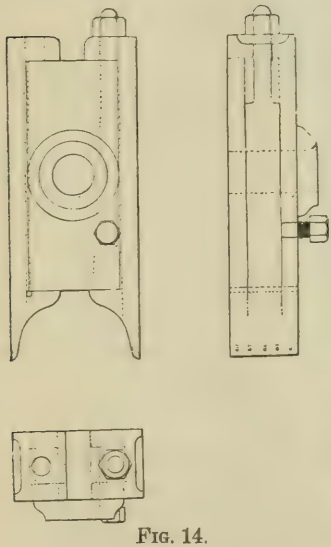


Fig. 14.

The pressure of the steam upon the back of the slide valve is

partially removed by an automatically packed balance ring, the invention of William B. Robinson who patented it in 1864, he being at the time the mechanical engineer of the firm of Jackson & Wiley of Detroit, Michigan. Speaking from my own experience in the use of this invention on a large number of engines, I will say

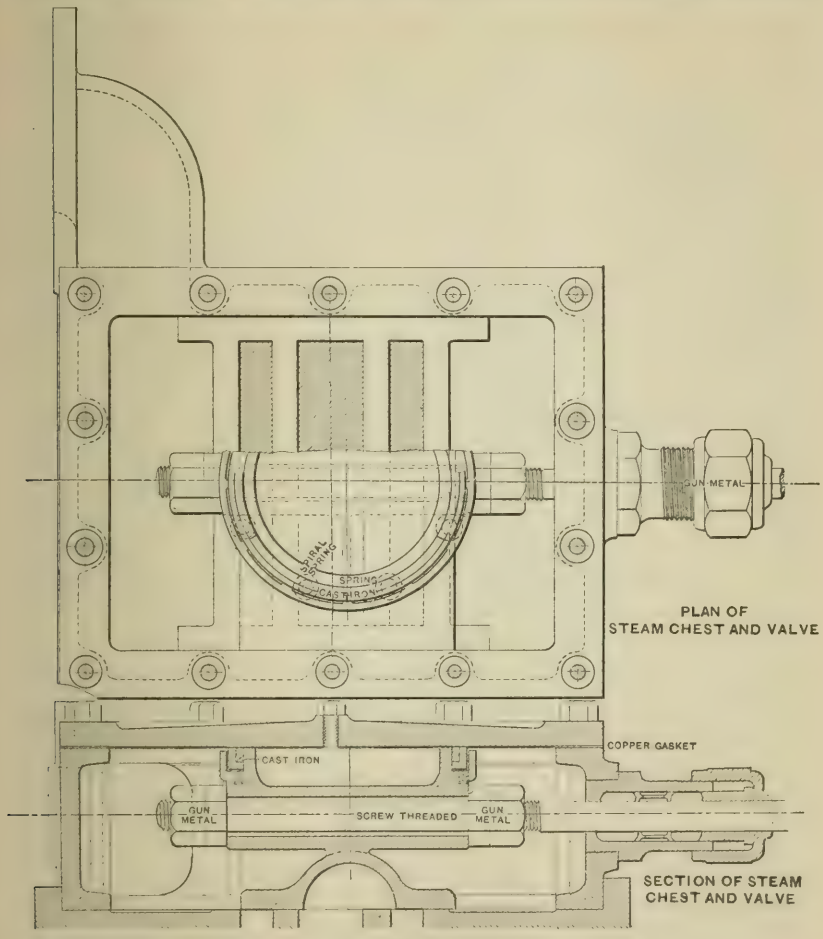


Fig. 12.

that it deserves to be much more widely known and generally used than it has hitherto been;—it does not pretend to be a perfect balance, that is, to relieve the valve of all the pressure upon it, but by its use the objectionable steam pressure is very materially reduced. In fact, in my own practice I have found it convenient so to proportion the balance ring, that sixty per cent. of the pressure of steam was removed from the back of the valve when both steam

ports were closed. The construction of this balance ring is very simple ;—the steam chest cover is planed off on its under side, but the body of the slide valve does not quite touch this surface. On the back of the valve is a circular groove which is truly turned; in this groove is placed a compound ring made of cast-iron. This ring consists of an outer member of L section inclosing an inner member of rectangular section, as is plainly shown in the section of the valve in Fig. 5. The two members of the compound ring are cut transversely into the same number of segments and are so located with respect to each other as to break joints (see Fig. 12). This compound ring is supported by a number of spiral springs of brass wire which are strong enough to sustain the weight of the ring in contact with, but without exerting of themselves an undue pressure upon the steam chest cover, their object being simply to keep the ring from dropping away from the cover when the steam is shut off. When the engine is in motion the steam acts upon the under and outer side of this compound ring pressing it into steam tight contact with the planed surface of the steam chest cover, and the smaller circumference of the turned groove in the back of the valve within which the ring is placed, thus preventing all access of steam to the space inclosed by the ring. In order to ascertain whether the ring is acting as it should, it has been my custom to put a common try cock in the centre of the steam chest cover, which cock is always left open and any leakage of the ring is at once manifested by the escape of steam from this open cock.

In case of any undue accumulation of water in the cylinder the valve will leave its seat with even greater ease than the ordinary unbalanced valve. The dead weight of the slide valve is balanced by a counter weight on that arm of the rocker shaft which is coupled to the excentric. The stuffing box of the valve stem is constructed in a similiar manner to that of the steam cylinder already described.

I will now call your attention to the most prominent peculiarity of the construction of this engine ; the mechanism for balancing the dead weight of those reciprocating parts connected to the main piston. The piston rod is secured to the piston by two gun metal nuts, the rod where it passes through the piston being enlarged as shown in the drawings ; above these nuts the piston rod is prolonged of the same diameter as it is below the piston, and passes through a stuffing box in the upper cover of the cylinder and then enters a small cylinder in which it has attached to its upper extremity a small piston. The stuffing box just named is of a very

old and also of a very uncommon construction ; the only instances in which I have seen it employed are in machinery of my own design, and I know of but one work, and that was published thirty years ago, in which it was ever illustrated; and I will say before describing it that I have found it to work very satisfactorily in practice.

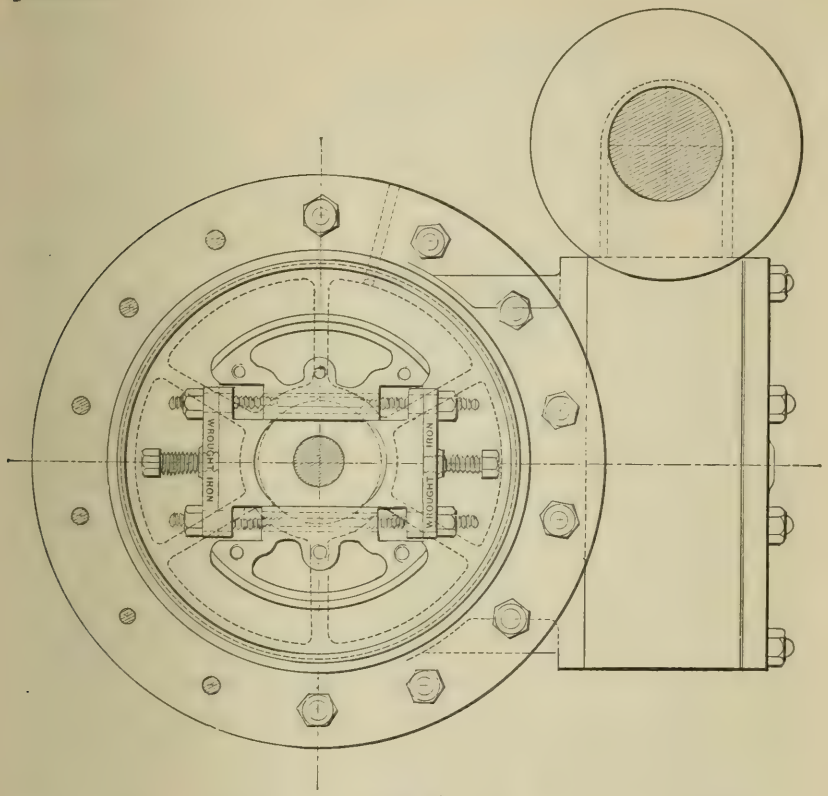


Fig. 11.

The space intervening between the upper cover of the main cylinder and the lower end of the small cylinder resting upon it in the immediate vicinity of the piston rod is occupied by this peculiar stuffing box, which may be described as a channel having parallel planed sides with open ends, the bottom of the channel being formed by the top of the cylinder cover, and its top by the bottom end of the balance cylinder. The otherwise open ends of this rectangular channel are closed by two gland blocks, which are made to compress the packing around the rod sideways, by means of set screws acting against their centres, said screws passing through

wrought iron plates whose ends are united by two equalizing bolts as is show in drawing (Fig. 11). By means of these bolts it will readily be seen that all strain upon the piston rod tending to force it laterally is avoided while at the same time the packing is effectively compressed. The small piston to which the upper end of the piston rod is attached is so proportioned that when steam of boiler pressure acts upon its under surface the upward pull due thereto is sufficient to balance the dead weight of all the vertical reciprocating parts. Steam is supplied to this cylinder through an $1\frac{1}{4}$ inch pipe connected to the main steam-pipe between the throttle valve and the boilers. The cylinder is therefore always filled with steam whether the engine is in motion or not, unless indeed a stop valve in the small pipe usually open is closed. When the engine is in motion the steam passes freely into the small cylinder below its piston on the up-stroke of the engine and out of it into the main steam-pipe on the down stroke, there being no loss save that which results from radiation. The air and dust is prevented from entering the balance cylinder on the descent of the piston, by closing its top by a brass dome casting, but as the space above the small piston will certainly become filled with air or steam, and possibly some water, should the engine remain standing for some time, provision is made for getting rid of these by a drain pipe communicating with the channel around the top of the cylinder, in which pipe is placed a "check valve" opening outward. Thus at the first upward stroke of the engine everything above the small piston is expelled, which action will of course leave a partial vacuum in the small cylinder above its piston on its down stroke:—advantage of this fact is taken in determining the size of the balance cylinder, and by making proper allowance for the value of the vacuum the area of its cross section is made smaller than would otherwise be advisable. The engine whose leading details I have described to you, ran absolutely silent, with no vibration in its frame, and with an easy buoyant movement of its reciprocating parts that excited the surprise of all who saw it; it was handled easy by hand and did not annoy its engineer by showers of scalding water from its stuffing boxes.

I regard a well designed inverted direct acting engine as in every way preferable for most purposes to any form of horizontal engine for the following reasons:

1st. It has much less frictional resistance.

2d. It occupied much less floor space. This, in the case of engines

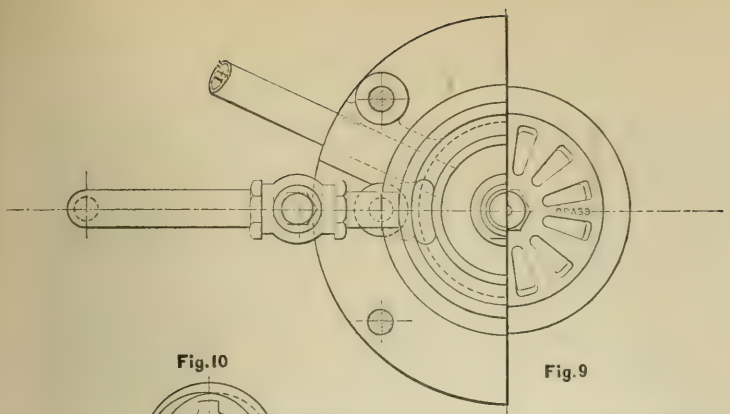


Fig.10

Fig.9

HALF PLAN OF CYLINDER

HALF PLAN OF COVER

PLAN OF PISTON

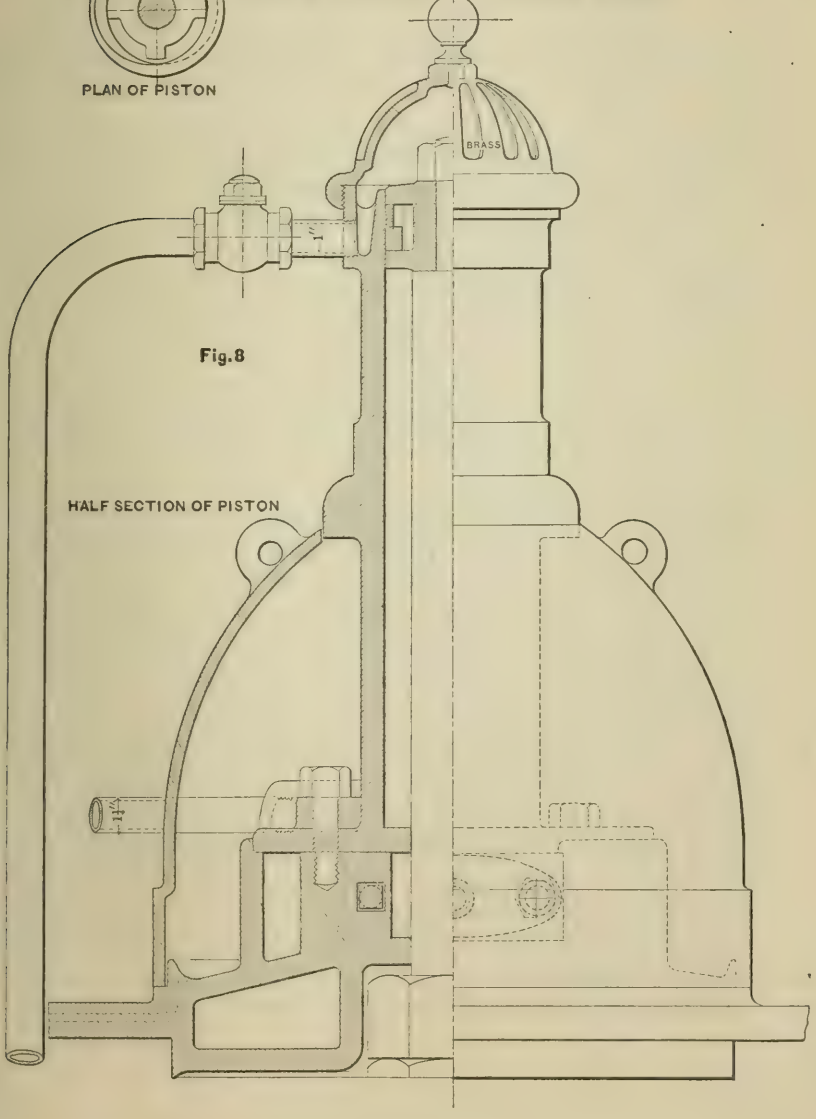


Fig.8

HALF SECTION OF PISTON

in larger cities where real estate is of daily increasing value, is no small advantage; electricians appreciate this, and now that the electric light has apparently come among us to stay, compactness in the arrangement of machinery for its production is regarded as very desirable.

3d. It is capable of higher speed than the horizontal engine. This feature will commend itself to all who regard power as mainly consisting of space and time, with but very slight seasoning of pressure.

4th. The foundations required are much less both in mass and cost.

5th. A vertical engine can be erected in a contracted position difficult of access with greater ease than any form of horizontal engine.

I do not wish it to be understood that I prefer the slide valve to all other forms of steam distributing mechanism. Any form of valve gear desirable can as readily be applied to a vertical engine as to a horizontal, and in the engine illustrated I used the slide valve because under the conditions existing I thought it the best adapted to meet them.

DISCUSSION.

Mr. Henning.—I would like to ask what advantage it is to put the holding-down bolts in the block so that you cannot get at them without taking the cap off?

Mr. Durfee.—The advantage is compactness, cheapness, and neatness in every way. I will say I have not had one of those holding-down bolts get loose in all my experience. Perhaps they do sometimes. Still, if they do get loose, it is very easy to get that cap off; it takes but a short time.

Mr. Henning.—What is the advantage of filling the base with brick before you set it down?

Mr. Durfee.—The object of that is to insure the distribution of the weight of the frame over the whole area. If there was no brick work, the frame would only have a bearing upon the foundation on the sides, and the edges of the stiffening ribs; but by putting that brick work in and running grout under it you have a solid bearing over its whole area.

Mr. Henning.—Did I understand you to say you put one-quarter inch of grout under it?

Mr. Durfee.—About a quarter-inch of grout, yes.

Mr. Henning.—Will you please tell me how you get it in, unless you make it very thin?

Mr. Durfee.—It does not require to be very thin; you can push it in with a rod from all sides until it comes out in the crank bed, which goes over the whole frame, and it is very easily calked in.

Mr. Henning.—Did you say your bed-plate was about six feet square, with a quarter of an inch of space between it and the foundation?

Mr. Durfee.—Yes.

Mr. Henning.—And you get a good grout in there?

Mr. Durfee.—Yes. In some places there might be three-eighths of an inch; if it was half an inch it would not matter. I am speaking of the principle more than the precise thickness.

Mr. Henning.—I attempted the same thing in several hundred cases with beds about 28 inches square—varying from 28 to 32 inches square—and it was not successful. I could fill it with a very weak grout, but by using a good grout, which kept the superstructure where I had it, I could not do it at all.

Mr. Durfee.—I will say in reply, that in my own experience I have not only been successful in the engines I have put up myself—I have had three of them put up under my own supervision, and I have also put up very heavy castings—in one case they were four feet square with no hole in them, and ran the grout in from one side with a dam of clay around; and it worked entirely satisfactorily.

Mr. Henning.—Another question. You have remarked that a vertical engine can be made to run at a higher speed than a horizontal engine. Will you please state the reason why that is so?

Mr. Durfee.—I state it as the result of my thought and experience in connection with the subject. I think there is every reason why an engine balanced in that way should run faster than by any possibility you can make a horizontal engine run.

Mr. Henning.—Is there a vertical engine running to-day which runs as fast as high speed horizontal engines?

Mr. Durfee.—I cannot say, sir. I do not know how fast the high speed horizontal engine runs, but I should not be afraid to run that engine a thousand feet a minute.

Mr. Henning.—I had never heard of a vertical engine that ran at as high a speed as the Porter-Allen, or the Buckeye engine.

Mr. Durfee.—At how high a speed do they run?

Mr. Henning.—I forget the exact number of feet of piston speed. Mr. Leavitt probably could give us better information on that.

The President.—They run up as high as nine hundred feet; that is the highest I have ever known.

Mr. Durfee.—This engine ran without a particle of vibration. When there was no noise from the machinery adjacent to the engine, you could stand and put your hand on the frame of that engine and you could not tell whether it was running or not. It was running seven hundred and fifty feet a minute. I should not hesitate to run an engine of that size a thousand feet a minute.

Mr. Scott.—Mr. Chairman, I would state in connection with this matter of grouting bed-plates that I have had considerable experience, not only in putting down foundations for engines, but under machinery of a very heavy class, such as is used in the manufacture of gunpowder, where we have a bed-plate from eight to nine feet in diameter, on which move heavy masses of cast-iron in the shape of rollers. We have a shifting weight of from eight to ten tons on each side, and those shifting weights are much more difficult to maintain a foundation under, than the ordinary engine. We always put those down in grout by building an ordinary stone foundation, and the bed-plates have a central hole in them, and where we make bed-plates under the engine we very often make the foundation with a large stone or with a cope-plate. We have holes through the bed-plates or cope-plates, and we use the ordinary foundryman's trick of forcing that grout in by putting in a stand pipe, through which the cement is introduced. I have grouted cope-plates on the top of a pier for setting a Corliss engine, where I have driven it over a surface seven or eight feet in width by as much as thirty feet in length, having a quarter-inch space between the plate and the masonry. You can make that grout of any consistency you please, and even quite thick. (Applause.) I have sometimes put up a stand-pipe as high as eight or nine feet, and I can lift the bed-plate or force the cement through the smallest opening by the hydrostatic pressure. It is merely a matter of building the pipe up to a sufficient height.

Mr. Henning.—That covers my point exactly. I can get the grout in and make a good bed by putting it in under pressure.

Mr. Scott.—We do that thing when there is no opening through the plate, by just putting a stick of timber on the outside of the frame with a rabbit under it. That makes a channel around the

entire frame. Weight that with stone and put up a pipe or four pipes, one on each corner. I have done that.

Mr. Hewitt.—In regard to the speed at which horizontal engines can be run, I can state that the Trenton Iron Co. have a horizontal Corliss engine 20 × 42, making 160 revolutions per minute, or a piston speed of about 1,100 feet. This engine has been in constant use running at this speed for about seven years, has required but very few repairs, and is still in fair condition. A description of the engine will be found in a paper on "The Continuous Rod Mill of the Trenton Iron Co.," which I had the pleasure of reading before this society at the meeting in Hartford.

Prof. Webb.—Mr. Chairman, I would like to ask the question, whether the vibration of an engine depends directly on the piston speed. The piston speed alone has been spoken of in two or three remarks. Now, does it depend upon the piston speed alone? That is, will two engines having the same piston speed necessarily vibrate the same or require the same stability in order to keep them from vibrating?

Mr. Le Van.—I think it does not depend on the piston speed as much as on the number of revolutions the engine makes. I had a small engine in my shop that ran 300 revolutions a minute for about ten years, and had no trouble at all with it. The change of motion affects the foundation; it is not the piston speed.

Mr. Webb.—I think, Mr. Chairman, it would depend on the piston speed *and* the number of revolutions, as far as it depends on either of them. If two engines have the same piston speed and one has double the number of revolutions that the other has, then the accelerating force will be twice as much in the former case as in the latter. The piston of one engine will come to its maximum speed in half the time occupied by the other in reaching the same maximum, and in doing so it will move over only half the space, therefore, the force required will be doubled. This is about the state of the case when the engine is running with steam turned off; but if the steam pressure used is the same on both pistons, then I should say that with steam on there would be but little difference in the steadiness of the two engines, except for one fact. The main reason why an engine properly set up will sometimes vibrate is that it often finds the foundation, etc., ready to vibrate in unison with it, and this is more apt to be the case when the time of vibration is short, and such rapid vibrations are more noticeable. If an engine be properly constructed in itself and

properly set up, I do not see that serious vibrations are any more to be feared in a quick than in a slow running engine.

The President.—It would seem to be a question of the weight of the parts and the stability with which they were held down. I suppose that if we had a cylinder of 20 inches and we had mass enough to attach to it, it could be run absolutely without vibration, even if the parts were not balanced; but probably it would be destructive on the parts after a while.

In regard to the speed of vertical engines, if I remember correctly, I saw an engine run a thousand revolutions a minute at the Delamater Iron Works, but Mr. Miller can tell me if I am right about that.

Mr. Miller.—Yes, sir; it is a vertical engine driving a dynamo, and has been running during the past two winters about four hours per day, developing ten horse power and making 1,250 revolutions per minute.

Mr. Comly.—Will the gentleman please be so kind as to mention the stroke of the engine?

Mr. Miller.—It has rather a short stroke, only three inches.

Mr. Comly.—That would, of course, make considerable difference.

Mr. Hamilton.—I would like to ask the gentleman whether he had any trouble in regard to the balance valve floating up. I have had some experience with that kind of balance slide valve, and I found that if the valve was adjusted so as to use the necessary compression for a quick-running engine, the valve would float up, allowing steam to blow through. I have been compelled to reduce the compression until the valve would keep its seat.

Mr. Durfee.—That is a question of the proportion of the ring to the area of the valve. If you get that ring too big, you can do that—I have no doubt about it. But in this case I have had no difficulty with it at all.

Mr. Baldwin.—I would like to ask what effect the changes in initial pressure would have on that piston?

Mr. Durfee.—The changes that occur in boiler pressure in the case of engines that were run under my own supervision were so slight that there was no apparent effect on the engine. The boiler pressure was kept within a few pounds. The engine is calculated for a particular pressure. You would have to know what your boiler pressure was when you built your engine, or adapt the boiler pressure to the engine.

Mr. Thomas R. Morgan, Sr.—Mr. President, does it not seem

reasonable, in comparing the vertical with the horizontal engine, to consider the weight of the piston and its connecting parts? Would they not have a tendency to be very hard on the vertical engine, in comparison with the horizontal? That weight is taken off in the horizontal engine, while the vertical engine generally has it. There is hardly any way of balancing by which you will not have that dead weight downward. That certainly must be very hard on the down stroke. That you do not have to contend with at all in the horizontal engine. It seems to me that is very largely in favor of the horizontal engine in high speed.

Mr. Durfee. I will say in reply to that objection that that was the very reason that balance piston was put on. By putting the balance cylinder on you annihilate the dead weight. That balance cylinder sustains all that dead weight. The piston practically weighs nothing.

Mr. E. Comly.—May I ask if that arrangement of balancing the piston is not the same as is used in balancing the valve stem and valve gear on large marine engines?

Mr. Durfee.—I will say that that principle is precisely the same, and that the balancing of valves in that way has come in use since this patent was issued. This was before the time that any valves were balanced in that way.

The President.—The Chair would remark from personal observation that any well-built engine of any type, whether vertical or horizontal, can be made within reasonable limits to run satisfactorily smoothly, and though in his own practice he has preferred to have the cylinders of large engines vertical, the practice of other people for whom he entertains great respect has been to build horizontal engines; and we shall see to-morrow at the Otis Steel Company's a forty-inch horizontal engine, which I think will please every one of us. It is simply a matter of properly balancing the parts, making the static parts of the machine heavy enough, and in addition to that making about four times as much foundation as seems to be necessary. (Applause and laughter.)

Mr. Durfee.—Mr. President, I think your remarks are a very strong argument in favor of the vertical engine. (Laughter.) We get in it a minimum foundation and a minimum friction. In these quick working horizontal engines the piston is traveling over the length of the cylinder very frequently, and I have known some of them, after a very few years' run, suffer very seriously on account of the friction of the piston.

Mr. Sweet.—Mr. President and gentlemen, I believe it is not usual to continue the discussion after the President has made his final remarks, but as others have spoken I would like to say a few words.

We have an engine which we can balance very readily, with fly-wheels each side and close to the crank. We can put the counter weight where we please. I had accepted Mr. Porter's mathematical conclusions as correct [he has always been my patron saint on steam engineering] (laughter), and put enough weight in the fly-wheels exactly to counterbalance all the reciprocating parts. Our partners in Chicago have not been satisfied with the running of the engines, and have been experimenting. They took two engines and balanced them, on the plan we were following, then took weights and added to the fly-wheels, shifted them from one place to another, increased and diminished the weight, until they got the engines so they say they run better than any engine we have ever built.

Now, the remarkable thing is that in an engine 8x14 in size, running 250, balanced as we balance them, they put in 35 pounds of metal in the rim of the fly-wheel, which has a radius four or five times the length of the crank—35 pounds of metal, and that on an engine where the reciprocating parts weighed about 195 pounds. And what is more strange, the weight is not opposite the crank; nor is it on the crank side; neither is it 90 degrees from the crank, but, as nearly as I can judge, 15 degrees back of the crank. These engines run, they say, perfectly quiet, not only on a solid foundation, but on an unstable foundation. They propose to continue these experiments on every engine and keep a record of them, and we propose to do the same thing independently; if we arrive at the same conclusions, we think we will have settled something that will be of value about balancing an engine.

Mr. Scott.—Mr. President, I wish to indorse one remark made by you in regard to the foundation of engines. There is one method of making a cheap foundation that is not understood, perhaps, as well as it should be. I will mention an experience I had in setting one engine. It was a horizontal engine, about 14 inch cylinder. It was put down on ground that was a little soft. We dug down some eight or ten feet, and we had a fairly good foundation. Then we piled it the best we could, and we put in the ordinary stone structure, set the engine and started it, and we found the ground was so soft we could feel the vibration of that engine

outside of the building where it was placed and 30 or 40 feet away from the foundation pier, and we were in a fix. We did not have time to take it up, and would not have known what to do if we had taken it up; but as an experiment I excavated a trench which was an extension of the foundation of the engine, lengthwise, for a distance of about 60 feet, and I filled that trench with firm material and rammed it down. I filled in about half of it first, and we started the engine. We found the vibration nearly ceased. Then I extended it about 30 feet farther and rammed that trench full, and we killed the vibration, and since that I have adopted the old farmer's method of digging a post hole and setting a post, by filling it with material and ramming it down, and I have found that answers as well as stone in a great many cases.

BÉTON IN COMBINATION WITH IRON AS A BUILDING MATERIAL.

BY

W. E. WARD, PORT CHESTER, N. Y.

If society is indebted to the restless spirit of progress for most of its modern comforts and conveniences, it certainly is not yet a debtor for any methods which guarantee immunity against calamities from fire. While other departments of industry have received the benefits of improvement, the continuous and persistent use of combustible material for exposed portions of buildings has limited the intrinsic elements of the art of building construction, and confined improvements only to matters of design.

Incombustible materials are easily obtained and much better adapted to the purpose for every apparent reason. Doubtless the question of increased cost, both in money and in time, required for more thorough construction may be in a measure responsible for the tardiness in adopting safer methods, and, in addition to greater expenditure, there may have been a want of confidence in the fire-proof methods which have been offered to the public for adoption. The importance of this question induced the writer, in 1871 and 1872, to make some experiments in a new and special direction, for the purpose of ascertaining whether a practically fire-proof building could be designed and constructed at a comparatively moderate cost.

The incident which led the writer to the invention of iron with béton occurred in England in 1867, when his attention was called to the difficulties of some laborers on a quay trying to remove cement from their tools. The adhesion of the cement to the iron was so firm that the cleavage generally appeared in the cement rather than between the cement and the iron.

The line of experiments which followed were confined exclusively to working up the reciprocal value of béton, in combination with iron, in the construction of beams which were designed for supporting floors and roofs made of the same material. In this particular, the facts were conclusively developed, beyond question, that the utility of both iron and béton could be greatly increased

for building purposes, through a properly adjusted combination of their special physical qualities, and very much greater efficiency be reached through their combination than could possibly be realized by the exclusive use of either material separately, in the same or in equal quantity.

Experience had long ago proved that unprotected iron, associated with combustible materials, is altogether unreliable for building purposes when exposed to a severe fire test; but it has been demonstrated that if iron is well protected by a heavy clothing of béton, its integrity can be safely depended upon under almost any emergency.

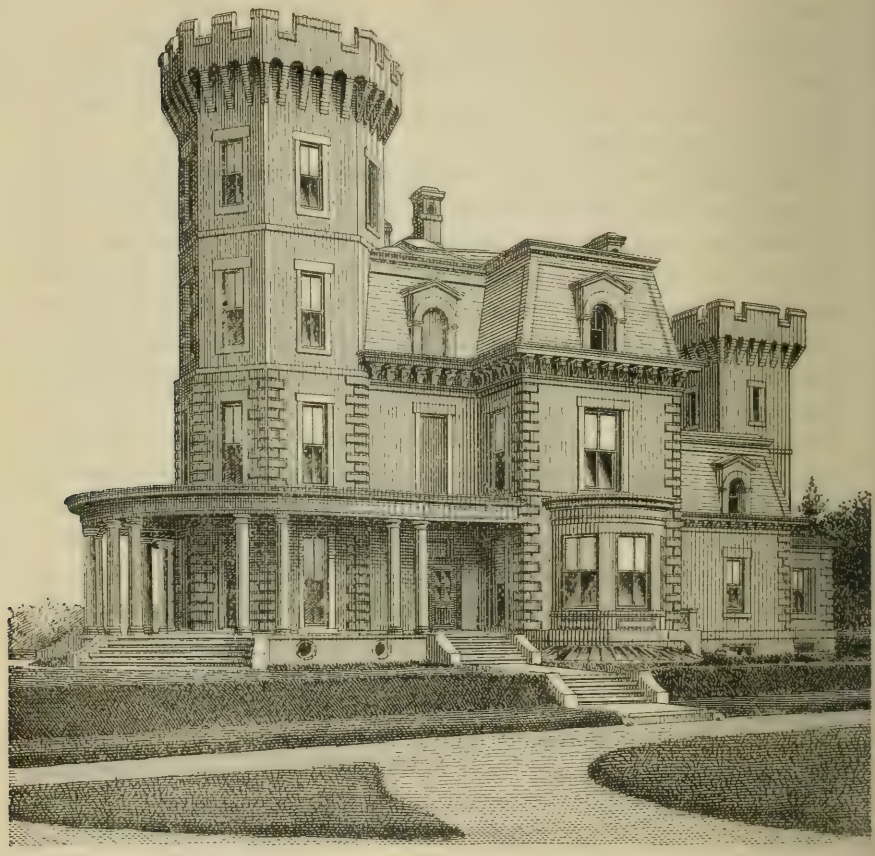
When all doubts were removed concerning the reliability of the several combinations of materials required in the construction, a building embracing the following radical new features was erected, for dwelling purposes, near Port Chester, N. Y. Not only the external and internal walls, cornices and towers of the building were constructed of béton, but all of the beams, floors and roofs were exclusively made of béton, re-enforced with light iron beams and rods.

Furthermore, all the closets, stairs, balconies and porticoes, with their supporting columns, were molded from the same material. The only wood in the whole structure was in window-sashes and doors with their frames, mop-boards and the stair-rails; thus excluding everything of a combustible nature from the main construction.

Béton can be used in any form of construction, and is able to serve the requirements of any architectural or decorative effects. All the exterior portions of this house, which are more or less ornamental in their functions, were made of béton in place during the progress of the work. In the interior of the house, the cornices, stiles, and panels of the ceiling are formed of béton, and covered with the hard finish usual in such work. There appears to be no limit to the reproduction in béton of any form used in stone masonry or in stucco. The proportions of material composing the béton for the work varied in strength to meet the requirements of the different parts of the structure, the heavy walls needing the least proportion of cement, while the beams, floors and roofs required a much larger proportion. Only the best quality of Portland cement, clean beach sand, and crushed bluestone were used in combination with iron for constructing the building.

The proportions of cement used for the heavy wall work were one part of cement to four parts of sand and fine gravel, thoroughly mixed dry, and dampened with only sufficient water to give it the consistency of well-tempered molding sand.

A finely crushed and screened hard blue limestone was found



VIEW OF THE HOUSE.

to be better adapted for use in combination with the béton than a coarse-sized stone filling, because small-sized stones pack closer than large ones, thereby realizing a proportional saving in cement. The tests made to ascertain the comparative transverse strength of different compositions proved that the bond was stronger in béton made with small stone. In breaking test-sections made of béton in the form of bricks, the fracture of those filled with small stone

was almost invariably across the stone lying in the line of fracture, while the fracture of the test bricks made with a filling of stone three or four times larger, showed a frequent tearing away from the bond between the béton and the larger stone filling, the composition of the béton being the same in both cases.

The proportions of cement and coarse beach sand and gravel, used in re-enforcing iron beams for floors and roof supports, were one part of cement to two parts of sand and gravel. The size of the iron beam, selected for an experimental test, was a four-inch I beam of lightest pattern, twelve feet long, weighing thirty pounds to the yard, and its safety load was limited to eleven hundred and fifty pounds. A plank mold was made the length of the iron beam, twelve inches deep by five inches wide, in the bottom of which a layer of béton was first moderately tamped down to an inch in thickness; then the iron beam was laid on the course at equal distances from each side of the mold, and settled down on the surface of the course of béton to a good bearing. This brought the top surface of the beam seven inches below the top of the mold. The work of filling and tamping the courses was then continued until the mold was filled.

The reason for placing the iron beam so near the bottom of the mold was to utilize its tensile quality for resisting the strain below the neutral axis when this composite beam was exposed to heavy loads, while the béton above this line was relied on for resisting compression from load strain. The béton became thoroughly hardened in about thirty days, when the following tests of transverse strength were made. It was placed upon suitable supports, with a bearing of three inches at each end. A lever was adjusted so as to bring the testing load on a knife-edge bearing at the centre of the beam. Weight was then applied to the long end of the lever, until the stress on the centre of the beam reached nine thousand five hundred pounds. Under this load there was a deflection at the centre of the beam of seven-sixteenths of an inch, but not a sign of rupture appeared at any point.

The load was then removed, and the beam returned to the original line it occupied before the test, showing that the combination possesses the essential quality of elasticity in addition to the enormous increase of capacity to resist strain over that which was possible for either material to sustain if used separately and in the same quantity.

It is suggested for future construction that an inverted ⊥

beam would furnish a more preferable distribution of iron in the composite beams than the I beams which were used.

The result of this experiment demonstrated the reliability of the composite beam of iron and béton, and showed that the adhesion of the cement to the iron could be relied on under heavy strains; and warranted the adoption of béton re-enforced with small rods for the floors and roofs.

The beams for supporting the floors throughout the house were placed at such convenient distances apart as to insure perfect safety to the floors, and, at the same time, affording ample opportunities for producing the best effects in deep, paneled ceilings.

The beams were all molded in position, where they belonged, both for the floors and roofs, and after the same method that the experimental beam was made. The iron beams varied in width and weight per yard in accordance with their length and the prospective load; the largest being nineteen feet long by seven inches wide. When the combination beams were completed and ready for the floors and roofs, heavy planks were firmly placed in position and securely supported between the beams; the upper surface of these plank foundations being adjusted on a level with the top surface of the molded beams. These planks served as the bottom of the floor molds, and after the béton comprising the floor was hardened they were removed.

Channel ways had been molded in the walls, on a line with the top of the beams, for the purpose of supporting the outer edges of the floors.

Before the floors and roofs were laid, care was taken to cover all the supporting surfaces with paper, to prevent the adhesion of floor and roof sections to their supports. This precaution was necessary, to permit the movement of the floors and roofs that would unavoidably take place under varying temperatures and loads.

A part of the experimental system contemplated an attempt to warm the house by passing currents of heated air between the floors and ceilings, and up through flues made in close proximity to each other for that purpose, in the interior walls of the building, and it was necessary to core out a liberal area of lateral openings through the upper portion of the beams, in order to permit a free circulation of heated air. The ceilings rested upon flanges projecting from the lower portion of the beams, as shown in Figure 1.

Instead of using sand and gravel, or both, in combination with cement, for floor and roof construction, the preliminary experiments that proved the superior value of broken blue stone for massive work, led to the adoption of washed, fine screenings from the same material for the floors and roofs, because its greater angularity than gravel insured a stronger bond in the work than could be realized by using sand and gravel.

The proportions of materials used for this purpose were: one part of Portland cement to two parts of the fine stone screenings. The preparations being completed for laying down the floors, a thin course of the béton was first put on, and evenly tamped down to about an inch in thickness, over the whole space intended to be covered. Then rods of iron, five-sixteenths of an inch in diameter, were placed both longitudinally and laterally, at a uniform distance of eight inches apart, over the whole surface. Then, on this, a final layer of two inches in thickness was carefully tamped down. In about eight hours, the béton was hardened sufficiently to allow the application of the top surface, which was floated down with a half-inch coat of cement and fine beach sand mortar, made of equal parts of each. This completed the final finish, and made the whole thickness of the work three and a half inches. It will be observed that for the same reason as in beam construction, and, as before explained, the iron rods for re-enforcing were placed near the bottom of the work, so as to resist the tensional stresses due to the load, while that due to compression in the upper portion would be sustained by the béton alone. In this manner, and by this process, over thirteen thousand square feet of flooring and roofing were constructed to fill the requirements of the building.

The only test of any consequence upon the combined strength of the floors and beams together was made on a section of the widest floor in the house, where the beams are eighteen feet span and six feet between centres. Casks of plaster were placed upon the floor over the beam, forming a triangular load of thirty tons, which was sustained without any injury to the floor, or measurable permanent deflection. The dimensions of the beam that sustained this load were seven by sixteen inches, and eighteen feet span, re-enforced in its lower portion with a seven-inch I beam, weighing fifty-five pounds to the yard.

This test indicates that in addition to its admitted fire-resisting qualities, the re-enforced system of construction challenges comparison with other methods of building in matters of strength

and of cost, whether for buildings requiring long or short floor spans.

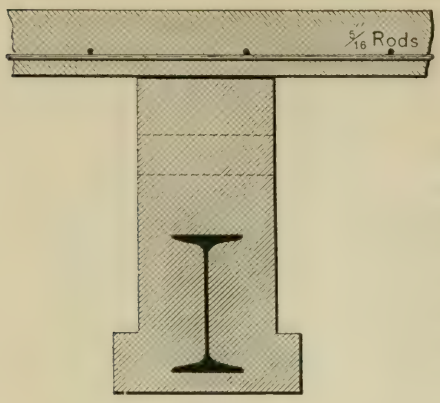


Fig. 1.

Experimental tests were made with several partition walls, to ascertain how thin it would be advisable to construct them for light walls where the load was small. The result of the experiment showed that the resistance of partitions eight feet in height made of béton two and a half inches thick, and re-enforced with one-quarter inch iron rods, was equal to brick walls eight feet high, and eight inches in thickness.

It is the opinion of the writer that for the great majority of houses required for dwelling purposes, a system of thin re-enforced double walls, with a space of from six to ten inches between them and re-enforced cross connections every two or three feet apart, to unite the outer and inner walls firmly together, could be built up to thirty or forty feet in height, at a cost not exceeding that of first-class brick work.

Besides an equal economy in the construction, such double walls would be an incomparably better defense against stormy weather than the best quality of brick work, because the absorptive capacity of béton is so much less than that of brick.

Thus, all things considered, the thin double wall system commends itself as containing the main desirable qualities essential to the outer and inner wall construction of dwelling houses, embracing, as it would, a sure protection against both fire and dampness, and the means for thorough ventilation. Besides the special fitness of the re-enforcing system for floors, roofs, beams and thin walls, it is an interesting question whether the same system may not be also applicable, and advantageously extended to a more general use in many engineering requirements: especially in situations where immense weights must be sustained, and where iron construction alone is difficult of application, notably in such an important work as the Hudson River Tunnel, where its tubular form is constructed with an outer cylindrical shell of flue iron, and

lined inside with heavy brick mason work; much of this tunnel rests upon a treacherous bed of silt, and might be made absolutely safe from a rupture caused by settlement, induced by vibrations resulting from railroad traffic in addition to its own weight, by adding to a thin brick lining a strong béton about sixteen or eighteen inches thick, and working in it three or four courses of iron bars, of suitable size, laid longitudinally and in sufficient quantity to bear any amount of strain that settlement or any other cause might bring upon it. Rings of flat bar iron, interspersed in the béton lining a few feet apart, would further add to its security.

Although the writer has no personal knowledge of the methods which are to be used in filling the interior of the statue of Liberty, to be erected on Bedloe's Island, New York Harbor, he is of the opinion that a filling of béton, re-enforced with iron, furnishes the best method of increasing the stability of that colossal statue.

The re-enforced béton system has also been employed with admirable results in heavy foundations for stationary engines. The writer, three years ago, mounted a two-hundred-and-fifty-horse-power tandem compound engine, of very heavy pattern, on a re-enforced béton bed, twenty-three feet long, five feet wide, and seven feet deep. It is apparently as firm and hard as a single mass of granite of those dimensions. The outboard bearing of the main shaft is also mounted on a single block of the same kind of construction. The cost of these foundations was less than the estimate made for the same in first-class brick or stone mason work.

It has also been used for lining a reservoir of 96,000 gallons capacity, which was blasted into a ledge.

Another great advantage realized in re-enforcing béton with iron, is that the iron overcomes its tendency to check in hardening, however large the surface may be, within useful limits, if the distribution of the iron through the work is made with ordinary good judgment. This is demonstrated in the instance of entire freedom from shrinkage checks in the single section of béton flooring laid in the drawing-room of the house under consideration. Its dimensions are eighteen by thirty-six feet, three and a half inches thick, and there is no trace of a check throughout its whole extent, after a period of eight years since it was laid down; and six years of that time it has been, during winters, more or less subjected to unequal strains from expansion and contraction, caused by its exposure to unequal temperatures, while employed as a trans-

mitting medium of heat for warming the room. The method of heating the house is shown in Figure 2, where the section of a portion of the house exhibits the arrangement of hot room and heating flues in the walls and floors.

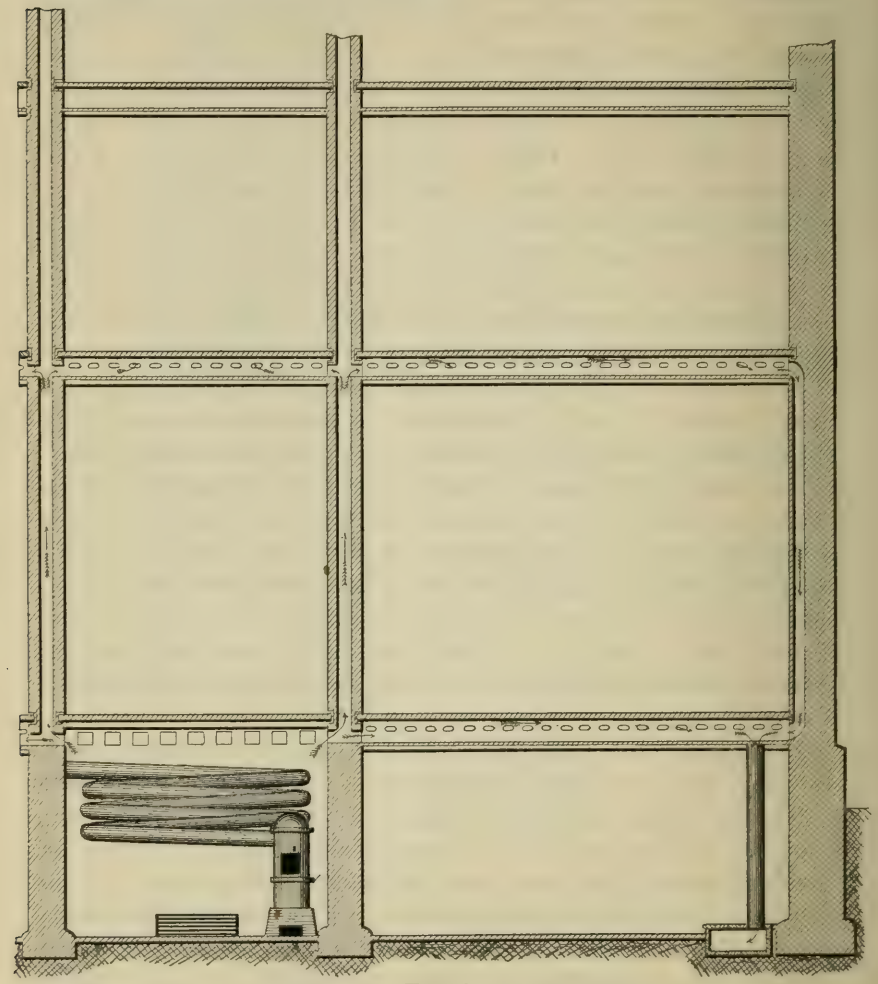


Fig. 2.

In the centre of the cellar is a heating chamber, measuring eleven by sixteen feet, and eight feet in height. Within this chamber is placed an ordinary cast-iron heater, of a capacity for burning about three hundred and fifty pounds of coal per day. Openings were made, about twelve inches apart, all around the top of the surrounding walls of the chamber, leading outwardly to the spaces between

the first floors and the cellar ceilings, and also up through the flues within the interior walls which communicate with the spaces between the second-story floors and ceilings beneath them. Vertical iron pipes, of suitable size, are located so as to connect the open spaces between the cellar ceilings and first floor with a large, closed trunk, or passage-way, which extends nearly all around the inside of the main wall foundation, under the cellar floor, and finally terminates in a large flue, which leads directly under and into the heating chamber.

This comprises about the whole system of arrangements in the construction for warming the house with heat radiated from the floors and interior walls.

Its mode of operation simply consists in the body of warmed air passing from the heating chamber upward, through the walls and under the floors, and in its passage giving up its surplus heat to the surfaces of these flues. As the air becomes reduced in temperature, it naturally descends back through the pipe and trunk passage-ways provided for its return to the heating chamber, where it is again re-charged with heat. It will readily be seen, that, by this method, a continuous circulation will be maintained with the same quantity of air; and, furthermore, that the velocity of the current will vary with the difference of temperature of the air when leaving the heating chamber and re-entering the heating chamber.

By this system there are about fifty-five thousand cubic feet of the interior of the house heated by radiation, through about thirty-five hundred square feet of floor and wall surfaces, and the capacity of the heating chamber is fourteen hundred cubic feet, so there is one cubic foot of heated air to forty cubic feet in the house.

The temperature of the air in the heating chamber averages, in very cold weather, one hundred and seventy degrees, and after delivering its surplus heat to the floors and interior walls, its temperature registers fifty-eight degrees in the flue where it re-enters the heating chamber for re-heating; showing that one hundred and twelve degrees of heat has been given up and utilized for warming purposes. With ordinary care in managing the furnace, a temperature of sixty-eight degrees can be uniformly maintained on the first floor, and from sixty to sixty-two degrees on the second floor, with a consumption of about three hundred and twenty-five pounds of anthracite coal per day in the furnace.

The temperature produced by this system of heating is free from the objectionable extreme variations so common with other modes

of heating. The walls and floor form such large heating surfaces that the temperature is uniform in all portions of the rooms, while the air is not vitiated by escaping gases or heated dust, as is universally the case where furnaces or steam pipes are used for heating.

It is not claimed that its economic result per pound of coal is greater than that which is claimed for the steam or hot-water systems, but if the latter were required to make as liberal a provision for the renewal of fresh air in the interest of an equally good ventilation, the percentage of useful results per pound of coal from steam or hot water would average no higher than the former.

The rain-water falling upon the roof passes through two six-inch iron pipes which are set in the walls, extend across the cellar, and reach into a béton tank in the rear tower, and holding 5,000 gallons, whose water level is thirty inches below the level of the roof. This inverted siphon also forms a distributing system to the various points of consumption in the house, through short branch pipes connected to these mains.

There are also two other tanks made of béton, and holding 3,000 gallons, situated under the main tank. One of these sustains a head of over twenty feet of water, and has never given any indications of leakage.

In regard to the important factor of cost involved in this system of béton construction, its average for beams, floors and roofs, including the supporting platforms for laying them down, was a fraction over sixty cents per square foot. This cost also includes the re-enforcing iron beams and rods. The cost of the heavy wall work, not including cornices, was about twenty-four cents per cubic foot, which includes the cost of plank molds required for building up the walls. The advantages that most favored these economical results were cheap material and cheap labor.

The bulk of the material required for the work abounds in inexhaustible quantities, and is always obtainable at moderate cost. The essential skill required consists in a simple knowledge of the right proportions of material, and of its proper manipulation, both of which can be acquired in a half-day's practice. The most inexperienced laborers can do all the work of the most elaborate béton construction, excepting only the surface finishing, and this, with all the other work, can be superintended by one competent, experienced builder.

Along with the foregoing data, it may be well to include an interesting feature of some experiments that were made to test the heat-enduring qualities of béton. A number of large test bricks were made of the same proportion of materials that was used in the construction of the walls, and in subjecting them to different intensities of heat to see how much they could withstand before breaking up, there was no perceptible difference observed in the tendency to fracture whether the bricks were exposed to a gradual or rapid heating. Not one of them broke when subjected to a white heat. Several were heated to a bright red heat, and then plunged into a bath of cold water. They withstood this test without showing a decidedly damaging fracture, and one of the bricks was exposed to an alternate heating and cooling three times before breaking up.

These results were a surprise, and they suggest the advantage of such a material for the walls of buildings, as a sure defense against uncontrollable conflagrations. The facts that appear to be established by this line of experiments are:

First: That a system of iron beams re-enforced with béton can be made to sustain weights many times greater than the iron beams alone can withstand without re-enforcing.

Second: That floors and roofs can be economically made of béton re-enforced with iron rods, capable of sustaining heavier loads, with a less number of supporting beams, than any other system of flooring and roofing now in use, *at equal cost.*

Third: That the system of re-enforced beams and floors afford advantages for a more perfect system of heating buildings uniformly than by the steam or hot-water systems.

Fourth: That the sanitary requirements of complete ventilation are plainly within the reach of this system of construction.

Fifth, and finally: That it affords a perfect defense against the interior destruction of buildings by fire.

The intrinsic worth of béton construction appears most valuable in furnishing the elements of fire-proof construction; and thus inaugurating a reformation in the prevailing system of building based on the principle that safety from loss by fire can be more economically realized through reformation than by exclusive dependence on insurance to indemnify for losses by fire. The amount of capital destroyed by such losses appears almost fabulous, and has been estimated by insurance authorities to be over one hundred million dollars annually in this country. This enormous amount takes no

cognizance of the losses due to the disturbance of business relations and to labor by such enforced interruptions of industry, but the sum of the losses accounted for seems to be enough to awaken an interest in the discovery of some effective remedy for reducing their magnitude.

Yet, if the remedy is only to be found in building more thoroughly, its adoption may remain doubtful so long as the hazardous way of building and the rates for insuring hazardous property occupy their present relations to each other. Such radical departures from conservative ideas of building, as are herein described, must necessarily find a slow recognition and reach public favor like any other innovation—through small and gradual beginnings—and wait until their merits grow to be regarded as a public necessity.

But, however destructive to the material wealth of the country may be the vast losses of property by fire, they sink completely out of view when compared with the terrible sacrifices of human life that are constantly resulting from unsafe building construction.

Against this fearful consequence of it, humanity can reasonably protest, and claim, for the sake of human welfare, that such structures as hotels, theaters, public schools, and all other places of public resort, shall be made invulnerable to the assaults and the horrors of fire catastrophes.

The writer has heretofore declined to make any public statement concerning the experiments herein described, for the reason that he considered they should undergo thoroughly satisfactory tests of severe weather exposures and varying temperatures through a period of time long enough to determine their true and relative value.

In conclusion, it is to be hoped that these experiments may shed enough additional light on the fire-proof building question to make the way easy for reducing re-enforced béton construction to a system that will deserve public confidence and ultimately lead to its common adoption.

DISCUSSION.

Mr. Grant.—I would like to ask why Mr. Ward did not build his new shop or bolt works on that plan? He has just built a new shop at Port Chester for making bolts. Why didn't he build his shop in that way?

Mr. Woodbury.—The foundation of a straight line engine which runs the screw works is built of béton. (Applause.) The shop in question is his son's—not W. E. Ward's.

Mr. Le Van.—Mr. President, I would like to state, in connection with fire-proof buildings, that the "Brown Building," just finished in Philadelphia from plans furnished by Cabot & Chandler and Amos J. Boyden, is considered fire-proof. All the floors and roofs are of heavy planks on wooden girders, the latter being re-enforced by iron plates or beams *only* where partitions may in future be removed, or where from other causes there may be great weight to support; and in all cases iron so used, has been inclosed in solid wooden beams, and both beams and ceilings thoroughly fire-proofed by heavy mortar coats on strong wire cloth.

All partitions are either brick or tile, and the upper surface of the plank floors is covered with a thick fire-proof mortar coat, over which the finished floor is laid and no *spaces* left for fire or vermin to lurk in.

Where spaces have been unavoidable (as between roof and ceiling in rear part) they have been *filled* with mineral wool.

The stairs are fire-proofed by iron casings, plaster and asbestos paper, and only a light oak finish left exposed.

The insurance companies of Philadelphia considered the risk so small that they have insured this building for five years at the rate of fifty cents on one hundred dollars, or at the rate of one-half per cent, the cheapest rate in the city.

Mr. Woodbury.—That mode of construction is old, and its utility has been tested for many years in New England mills; and this building was planned after a careful study of the principles of slow-burning construction advocated by the Mill Mutual Insurance Companies, and I believe that it is the only commercial building so constructed in this country. I have never known a floor made of plank covered with an inch of mortar to be burned through, although at Allendale, R. I., the whole roof of such a building burned off and endangered the surrounding property without the fire going down through the floor. It is, as far as we have had any experience, a practical impossibility for a fire to burn down through a film of mortar about three-quarters of an inch in the interior of the floor. It would require a great while for such a floor to be destroyed by a fire beneath it, although it would be quite possible. It would undoubtedly not happen until the columns of the beams were destroyed by fire. If the columns were of iron, of course they would yield when subjected to a slight fire; but wood will stand six or eight hours' exposure to intense fire before yielding. If the gentleman will take the trouble to refer to a

paper on mill floors which I read at the meeting in New York a year ago last November, he will see that method of construction described and illustrated by some sketches.

Mr. Le Van.—I did not mean to say it was new. I believe the French do this same thing. I thought from the fact of the rate of insurance being so low that there must be something in this manner of protection that is not generally understood by the community at large.

The President.—The Chair will state that the Zoological Museum at Cambridge is constructed in this way, the beams being covered with a fine covering of mortar attached to wire lathing.

Mr. Root.—Mr. Chairman, Mr. Ward being a neighbor of mine, I have been somewhat familiar with that house during the whole time of its construction. After it was completed he erected a large flagstaff right in the centre of the tower. This staff was supported by iron braces to hold it in place. There came up a very severe thunder storm, and the lightning struck this staff and shivered it into ten thousand pieces. The splinters fell all over the grounds around the house. A short time after that, hearing that the staff had been struck, I went up there, and we went up to the top of the tower to see what damage had been done. We found two or three little splinters of cement. The iron rods in the side walls and floors had served to carry away the electricity to the ground with such ease that no harm was done to the building whatever.

Mr. Weightman.—I would like to ask whether any difficulty has been found from dampness in a house with floors and walls of béton, with flues and ducts in them through which moist air will circulate in a wet season?

Mr. Thompson.—I rise to ask whether it does not take a long time for the béton flues to change their temperature from cool to warm and the reverse? Their necessary thickness and material, it would be thought, would act to make such changes sluggish and lead to trouble.

(*Added since the Meeting.*)

Mr. Ward.—Replying to Mr. Weightman's question, I would say that at no time since the house has been inhabited (which is now about six years) has there been seen the least indication of dampness in any part of it. I attribute its remarkable freedom from this trouble partly to unobstructed circulation of air through all the

walls and the spaces between the floors and ceilings, but mainly to the porous quality of béton, which seems competent to effectually resist any perceptible condensation of moisture. In answer to Mr. Grant's question, I have to say that the Port Chester Bolt Company, like many others entering upon a new enterprise, could not determine how much space they would require for their business short of one or two years' experience, and the building was urgently needed within less time than it would take to construct it of béton. Furthermore, the risk of the building and business from fire is so trifling, in comparison with that of most other manufacturing pursuits, it was not considered necessary to incur the additional cost required to build the factory of béton, although every part of it in the least exposed to dangerous fire risk, as well as the foundation bed of the engine, was constructed of re-enforced béton. To Mr. Thompson's question as to the time required for heating and cooling the house, I would say that a change of temperature in the house is sensibly felt within two hours after fire in the furnace has been started, and it takes altogether about five hours' time to bring the temperature of the space above the first floor up to 68 degrees, when the outside temperature ranges at about 30. To cool off the house rapidly, if necessary, it only requires, after the fire is let down, the closing of the dampers that control the circulation of the heated air and the opening of several windows to admit and discharge a large volume of out-door air. This will in about two hours reduce the temperature of the radiating surfaces from ten to fifteen degrees. Hence there is no serious discomfort experienced from the length of time needed for heating the house nor from reducing the heat when desired.

NOTE RELATING TO "WATER-HAMMER" IN STEAM PIPES.

BY

ROBERT H. THURSTON, HOBOKEN, N. J.

THE action familiarly known as "water-hammer" has been long observed by every engineer who has had much to do with steam power, and its singular effects have been often remarked and commented upon; but these effects have been developed on so large a scale, and have been so serious, oftentimes, in their consequences, as to make it seem desirable to examine into the matter more carefully than has yet been done. The writer has not been able to make a systematic and thorough investigation such as he would have liked to conduct; but some facts have been collected, a few of which will be here presented, that may at least have the effect of calling the attention of engineers more generally to this matter, and may lead to further study of the subject.

When a pipe is filled with steam, and then has introduced into it a quantity of cold water, or when a pipe, itself cold, and containing cold water, even in very small quantity, and without pressure, has steam turned into it, the first contact of the two fluids is accompanied by a sudden condensation which causes a sharp blow to be struck, usually at the point of entrance; and sometimes a succession of such blows occurs, which are the heavier as the pipe is larger, and which may be startling, and even very dangerous.

It is not known, so far as the writer is aware, precisely how this action takes place in all cases, or what conditions are most favorable to the development of the tremendous pressures which are often produced. Perhaps the action is as follows:

The steam, at entrance, passes over, or comes in contact with, the surface of the cold water standing in the pipe. Condensation occurs, at first very slowly, but presently more quickly, and then so rapidly that the surface of contact between the two fluids is broken, and condensation is completed with a suddenness that produces a vacuum. The water surrounding this vacuum is next projected violently from all sides into this vacuous space, and, crossing it, strikes upon the surface surrounding it. As water is nearly incom-

pressible, the blow thus struck is like that of a solid body, and the intensity of the resulting pressure is the greater as the distance through which the portion of surface attacked can yield is less. In this manner enormous pressures are sometimes produced.

In some cases it seems certain that such pressures may be caused at points in the pipe far from either end, and from the point of entrance of the steam. For example, a pipe may lie in a nearly or quite horizontal line, and, if not fully drained, may contain a considerable quantity of water lying in the lower portion, while the steam may flow in above it. The passage of this steam along the surface of the water may cause some disturbance of the surface of the liquid, and this disturbance being gradually increased as the flow of steam becomes more rapid, may finally cause a break in the surface of the water, which disturbance may produce more rapid condensation and still farther agitate the mass, until condensation occurs with such rapidity that a vacuum is formed at the point of greatest action. The next result is the rushing of steam from both directions toward this point, carrying with it, as it goes, masses of water which, coming from opposite directions with enormous velocity, meet at the intermediate spot at which the condensation has been most rapid, and being stopped by instant collision, produce a pressure which may only have as its limit the strength of the pipe.

Where pipes are not burst by this action, it is common to see them sprung and twisted out of line, torn from their connections and, when a succession of shocks occur, as is often the case, the whole line writhes and jumps lengthwise to an extent that is sufficiently serious to cause well-grounded alarm.

The writer had an opportunity to obtain some probably approximate measures of the intensity of this action in long and heavy lines of pipe. Four lengths of 8-inch pipe had been split in this way and it was desired to ascertain whether they remained, in their injured condition, strong enough to bear the ordinary steam pressure of the line from which they were taken. This never rose above fifty or sixty pounds per square inch. They were therefore subjected, in a proving-machine, to gradually increased pressures until the already fractured parts were still farther injured, the repairs, or rather the patching having been carefully done in such a way that they were not strengthened by it. This was done by putting on soft patches along the line of the pipe and securing them by bolts which were set in the line of the split. The patches

thus served as simple stop-valves, preventing the exit of the water through the break.

The following are the results of the tests:

Pipe No. 1.—This pipe was split near one end, for a distance of 15 inches, along the line of the weld. When placed in the proving-machine, it bore the applied pressure until it attained an intensity of 400 pounds per square inch, when the split suddenly extended about ten inches; the pressure could no longer be kept up, and the test terminated.

The pipe was then taken to a pipe-cutting machine and the injured part cut off. It was then again subjected to pressure. It bore a pressure of 1,100 pounds per square inch—the highest that it was convenient or customary to apply to that size—and was taken out sound.

Pipe No. 2.—This length was cracked for a distance of 15 inches along the line of weld, not far from the middle of its length. The crack had opened a little and the pipe was slightly bulged. This piece bore 300 pounds and then gave way, the fracture extending just enough to let off the pressure.

At the opposite end of the pipe was another split, 8 inches in length. The part just fractured was cut off, and the remaining portion was again subjected to the water-pressure. This time it bore 1,050 pounds per square inch when the crack was started and ran about 15 inches. It began leaking, and showed plainly the effect of the pressure at about 800 pounds.

This was an unusually interesting specimen, as the pipe had been bulged considerably by the water-hammer along the line of the 8-inch crack. The pressure afterward borne, therefore, seemed to the writer to be likely to be a fair measure of that produced originally by the water-hammer. Such bulging as was here seen never occurs at usual pressures. The new break did not follow the weld, but ran irregularly, and apparently indifferently, through weld or solid iron.

Pipe No. 3.—This length was split for a distance of 22 inches, the end of the break being about 3 feet from the end of the pipe. It sustained a pressure of 250 pounds. The sound part of the pipe was then tested up to 1,050 pounds without injury.

Pipe No. 4.—This piece was split, like the last, and to just about the same extent, was tested similarly, and gave way at 300 pounds per square inch.

All of this pipe was 8-inch pipe, $\frac{5}{8}$ inch thick, and made with the

usual form of lap-welded joint. The welds were not always perfect, as is probably the fact with all such pipe; but this pipe, butt-welded, would have borne very much higher pressures than those to which it was subjected in ordinary work, by the steam carried on the line. It cannot be asserted that these lengths of pipe did not split under pressures less than those to which they were afterward subjected in the tests, as it is very possible that the first blow may have found a weak part of the pipe, and the split may, in some cases, have extended to a stronger portions. Nevertheless, the writer is inclined to believe that this was not the case in all instances, and is convinced that, in one case at least—that of the 8-inch crack, which was accompanied by a decided bulge in the pipe—the water pressures, at the test, were, at least approximately, equal to, and are very likely to have exceeded, those obtained at the later test. It seems very certain that we may consider it as proven that the pressures produced by "water-hammer" are often enormously in excess of those familiar to us in the use of steam, and that they have, in many cases, exceeded 1,000 pounds per square inch. It is, then, evident that it is not often safe to calculate upon meeting these tremendous stresses by weight and thickness of metal, but that the engineer must rely principally, if not solely, upon complete and certain drainage of the pipe at all times as the only means of safely handling steam in long pipes, such, especially, as are now coming into use in the heating of cities by steam led through the streets in underground mains.

The facts here presented have been, to the writer, something of a revelation, and have seemed to possess unusual interest and importance to the engineer using steam under such conditions as are here referred to. It is a fact which has long been well known, that these suddenly produced pressures are often very great. The writer has occasionally, for many years, known of serious and sometimes fatal, accidents due to this cause; but that these stresses are often as great as is here indicated has probably been little realized by engineers generally.

DISCUSSION.

Mr. Chas. E. Emery.—Last fall the New York papers were filled with accounts of explosions of steam pipes, and in spite of all protests they refused, except in their advertising columns, to call attention to the fact that there were two steam companies in that city, and that the difficulties complained of were on the lines of but one of them.

Few read the advertisements, and the press outside of New York copied only the news items; so to this day there is a general impression all over the country that steam enterprise in New York has been a failure. While, ordinarily, engineering facts are valuable, without reference to time, place or persons, the above statement, with some explanations farther on, show the necessity in this case of stating at the outset that the New York Steam Company has been supplying steam continuously since April of the year 1882, while another company, viz., the American Heating and Power Company, upon whose plant, as is well known, Professor Thurston reported, actually ceased operations early in the winter of 1882–83, after a few months' abortive trial, and is now in the hands of a receiver, who is endeavoring to sell the property in the interest of the bondholders.

The phenomena of the water-hammer is familiar to most steam engineers, particularly those who have had to do with the large pipes used on ocean steamers. The writer, from his connection with the New York Steam Company, had full opportunity to observe the operations of the American Company, and is surprised to find in the paper under discussion no reference to what he considers one of the chief causes of the difficulty experienced in operating the pipes of that company.

It was actually and persistently attempted to carry superheated steam in their underground pipes. The regular superheaters provided were never used, but a series of pipes in the boiler settings answered the purpose to a certain degree, superheating the steam, it was said, some 60° or 70°—probably more at times, as the demand for steam varied; for who could regulate such an apparatus, or, in fact, in regular practice, any apparatus for such a purpose? The results are evident on consideration. The branches of the line where little or no steam was used soon cooled down, so as to contain only saturated steam, and at times all the branches were in this condition. Upon opening a valve anywhere, however, a circulation would be established, which slowly but surely would bring the superheated steam into that line, and all the conditions to produce unusual strains or cause even an explosion, would be present as soon as the steam reached any collection of water; for the reason that water, which is harmless in the presence of saturated steam of the same temperature, would act as an efficient refrigerator of steam at a higher temperature, though of the same pressure as that due to the temperature of the water.

The reduction of volume thus caused would not be as great as if steam were brought in contact with cold water, but entirely sufficient to cause a flow of steam from both—and at junctions from several—directions, some of the currents perhaps bringing more water to reduce the volume of more steam, thereby causing collision with a necessary great increase of local pressure, straining the pipes, causing the joints to leak at all sorts of odd places where there were apparently no reasons for the difficulties. The more violent explosions were undoubtedly due to a combination of the straining effects due to the reduction of volume of superheated steam, with the more potent one of direct contact of steam with water cooled during times of inaction; below the temperature due to the pressure, the forces being brought in action more strongly when the steam was conducted through one pipe to heat an adjoining one.

The conditions which brought about the bursting of the pipes undoubtedly varied with the circumstances of each particular case, and with the peculiarities of each location. Extreme business pressure prevents the writer from fully discussing the subject at this time, and its farther consideration must be left for a proposed paper on the general subject of "District Steam Systems," which it is expected will be prepared when all the problems necessary to a complete mechanical and financial success shall have been analyzed and the necessary apparatus put in practical operation.

NOTES ON STEEL.

BY

GUS. C. HENNING, M.E., PITTSBURGH, PA.

THE use of steel as a material of construction is becoming so general, that it is no longer a question whether we can obtain a material which can be relied upon, but merely when steel is used whether the sections of individual members will not become too light, when of the same strength as designs in iron, so that the structure will be destroyed by corrosion or minor accidents, rather than by use, unless unnecessary weight is added.

It is a well known fact that the sole reason why perfectly homogeneous Bessemer steel is not made in this country, is this: that there is a greater profit in steel for rails, with less work, than there is in steel for structural purposes, in addition to the fact that rails can be made in stock, but shapes cannot very profitably.

It is but quite recently that any attempt has been made to obtain a perfectly reliable and uniform material on a large scale, and then generally by using Siemens or Pernot furnaces.

In England, France, Belgium and Germany, the state of structural steel manufacture is far advanced, and for the simple reason that engineers in those countries insist upon a uniform material, and the quality of the output of any works determines its commercial success and progress, rather than location or political or personal influence. In this country the larger structures designed of steel are few in number, and the following table is a complete list to date.

DATE.	NAME.	ENGINEER.	SHOPS.	STEEL WKS.	WEIGHT OF STEEL. Tons.	CLASS OF STEEL.
	St. Louis Bridge.	J. B. Eads.	Keystone.	Butcher.	2,900	Carbon & Chrome.
1879–83	East River Bridge.	W. A. Roebling. Wm. Hildenbrand.	Edgemoor.	Cambria.	6,300	Bessemer.
1880	Plattsmouth Bdg.	Geo. S. Morison.	Keystone.	.....	497	Siemens-Martin.
1881–82	Bismarck Bridge.	"	Detroit.	Spang Steel & Iron Co.	....	.....
1883	Blair Bridge.	"	Keystone.	Cambria.	432	Open Hearth.
1883	Willamette Bdg.	"	Edgemoor. Passaic R.M.Co.	Spang Steel & Iron Co.	(?)600	"
1883	Niagara (New R.R.)	C. C. Schneider.	Cent. Bdg. Wks.	"		"
1883	Point Pleasant.	Col. Seymour.	Keystone.	"	(?)	"

The steel for these structures, as far as completed, was quite uniform in chemical analysis, as well as in mechanical properties, and

in every way superior to and more satisfactory than any grade of bridge iron from any mill.

Imperfect welds are not to be feared, as welding was in no case permitted; any hard spots could be easily removed by careful and thorough annealing.

It is true that some of this material was abused during fabrication, from want of knowledge of and experience in the use of steel, but this could have been prevented by proper procedure; where proper care was bestowed upon the work there remains no doubt about the superiority of the structure.

The quality or uniformity of the material used in any structure depends mainly upon the kind of inspection it receives at the steel works, while the quality of the structure depends upon the experience and care of the inspecting engineer at the bridge shops; if the former performs his duty faithfully and accepts only such material as is fully up to the specification requirements, and the latter watches closely every process during fabrication and prevents all abuse, there is but little doubt that a superior structure will be obtained. This, of course, requires experienced inspectors, whose judgment must be correct and based upon fact, and who, at the same time must be on duty at the bridge shops at all hours with the men.

Below is given a table, containing a number of tests of eye-bars which were recently made at the Keystone Bridge Works, and the results of which are equal, if not superior, to anything that has been done heretofore.

The tests as given in Table No. 1 were made upon bars fabricated by the following method:

The bars were at first heated in the neck, while the end was protected from the heat by a covering of refractory material; upon reaching a bright red heat, the bar was placed in the hydraulic upsetting machine and partly upset. Whenever this upset showed any wrinkles or uneven edges, these were drawn down under a helve hammer and fullered out. Then the bar was returned to the furnace and heated nearer the end, and again upset and worked under the helve hammer. Three heats complete such an upset, when the bar is again heated to a bright red and the eye is shaped in the hammer die, from which the bar is taken to another helve hammer, under which it is drawn down to the required thickness and given the correct set. This sometimes requires another heat before the end is finished, when the eye at the other end of the bar is made in the same manner.

TABLE No. 1.

Material.		Specimen.		Fractured Section.			Elast. Limit. lbs. per sq. inch.	Ultimate Strength. lbs. per sq. inch.	Elongation.		Broke from Pin Hole.		Excess.
		Size.	Area.	Size.	Area.	% Red.			In 13 ft.	%			
	14 ft. 4 in. c. to c.	5 × 1	4.80	.....	.....	44.1	41,800	72,700	.....	11.8	3 ft. $8\frac{5}{8}$ in.	$4\frac{1}{8}$" pins.	52.5%
		5 × 1	4.80	.....	.....	38.0	41,632	73,000	....	12.2	3 ft. $6\frac{1}{4}$ in.		"
		5 × 1	4.80	.....	.....	35.5	43,700	74,590	.....	13.0	8 ft. $2\frac{3}{8}$ in.		"
		5 × 1	4.80	.....	.....	35.2	44,272	75,130	.....	13.0	1 ft. 10 in.		"
		5 × 1	4.80	.. ...	.....	44.1	44,000	74,050	... .	13.5	8 ft. $3\frac{1}{4}$ in.		"
		5 × 1	4.80	.....	.....	43.7	44,000	73,330	.....	13.8	3 ft. $3\frac{1}{8}$ in.		"
	22 ft. c. to c.	$6\frac{1}{2}$ × 1	6.50	.....	.....	43.8	40,026	68,380	in 20 ft.	13.5	4 ft. $0\frac{3}{8}$ in.	5" pins.	38.5%
		$6\frac{1}{2}$ × 1	6.50	.....	.....	43.0	40,766	69,222	....	13.5	3 ft. 8 in.		"

Note.—Fractures were all perfectly uniform, showing a very fine crystalline structure perfectly homogeneous, and the broken surfaces showed perfectly symmetrical arrangement of material about the two axes; this latter is also a criterion that the strain was applied properly without disturbing influences.

Both eyes having been thus forged, the bar is taken to the annealing furnace, where it is subjected to a gas flame until attaining a bright red heat, when it is allowed to cool down very slowly until sufficiently cool to be handled. Then the bar is straightened in a bending machine, after which the pin-holes are bored in the head.

Thus it will be seen that these steel bars are subjected to four bright red heats and one annealing heat.

The bar is at no time allowed to reach a white or melting heat, and consequently the steel is not deteriorated, and but slightly altered in chemical composition, as has been shown by the series of tests made by Mr. J. F. Barnaby (see London *Engineering*, April 20th, 1883).

Table II. gives results of tests of three steel eye-bars—welded, not upset—made by the Springer patent process, from open-hearth steel made by the Spang Steel and Iron Co.; they were exhibited at the Railroad Exposition at Chicago, and the results were there given in a pamphlet from which this is taken.

The accompanying figure shows the method of manufacture:

The bar is first trimmed off at the ends to be round, and a bent bar of U shape is then placed around it to fit the bar closely; cover plates are then placed above and below, and the whole heated to a good welding heat, upon which the exact shape of head is formed under the steam hammer.

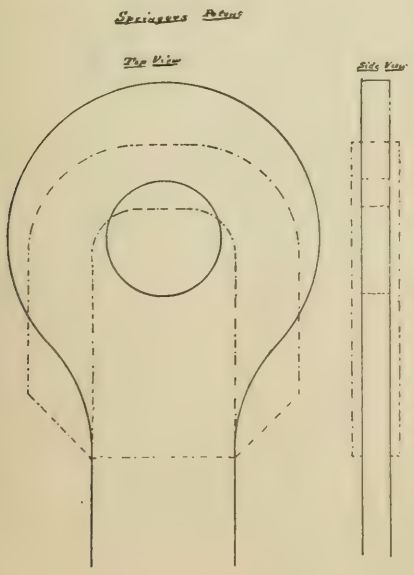


TABLE II.

Tests of Welded Steel Eye-Bars.

(Made According to J. H. SPRINGER'S Patent.)

SPECIMEN.		FRACTURED SECTION.			ELASTIC LIMIT.		ULTIMATE STRENGTH.		ELONGATION.		DISTANCE OF POINT OF FRACTURE FROM BACK OF NEAREST PIN HOLE.
Size.	Area in □ in.	Size.	Area in □ in.	% Reduct.	On specimen.	Lbs. per □ in.	On specimen.	Lbs. per □ in.	In 8 ft.	%	
5″ × 1″ × 10 ft. 10 in.	5	$4\frac{1}{8}$″ × $\frac{5}{8}$″	2.578	48.4	179,400	35,880	286,000	57,200	1.333 ft.	16.7	1 ft. $3\frac{1}{2}$ in.
5″ × 1″ × 10 ft. $9\frac{1}{2}$ in.	5	$3\frac{13}{16}$″ × $1\frac{1}{16}$″	2.621	47.6	178,100	35,620	289,900	57,980	1.542 ft.	19.3	2 ft. $7\frac{3}{4}$ in.
5″ × 1″ × 10 ft. $9\frac{1}{8}$ in.	5	$3\frac{15}{16}$″ × $\frac{3}{4}$″	2.953	40.9	175,500	35,100	291,200	58,240	1.738 ft.	21.7	2 ft. $4\frac{3}{4}$ in.

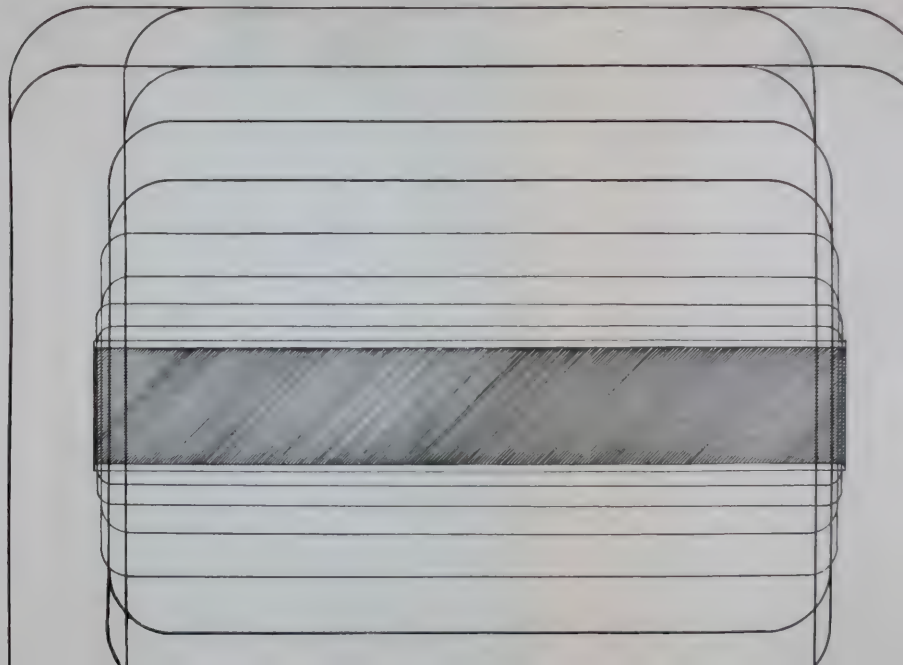
Heads $11\frac{3}{4}$″ diameter by 1 inch thick. Pin holes $4\frac{1}{8}$ in. diam. Bars were not annealed. Low Bessemer steel .10% of carbon.

Made by and tested at Keystone Bridge Works.

Fig. 2

SUCCESSIVE SECTIONS OF BILLET.

Roughing Passes
Area
55.68 sq.in.
47.62 " "
41.62 " "
35.62 " "
30.97 " "
24.72 " "
Time 5 min.



The appended report at the end of this paper contains the results of tests of six steel bars all $6\frac{1}{2}\times 1$ in., 22 ft. c. to c. of eyes, kindly presented to me by Mr. A. Gottlieb, President Keystone Bridge Co., which were tested at Watertown Arsenal, and were made by above process, of open-hearth steel made at Cambria Iron Works.

An inspection of this report will show that these bars are very uniform in most qualities, especially so in the elastic limit and the modulus of elasticity.

The entire method of manufacture of the steel is also given, as well as the chemical analysis of each head and bar, all bars having been rolled from the same blow of steel, and by the same method in a bar mill by the successive reductions as shown by Fig. 2, on which the sectional area of bar in each pass is given.

In the report of analyses supplied to me by Mr. George S. Morison, C. E., it will be noticed that in P_1 4585 and L_1 4587, the quantity of silicon is quite abnormal; this cannot be ascribed to the chemists, Messrs. Hunt & Clapp, of Pittsburgh, as independent analyses were repeated with the same results. As all the surface metal, about $\frac{1}{16}$ inch deep, was removed before collecting drill chips for analyses, the result must be ascribed to a peculiar composition of the heads.

TABLE OF CHEMICAL ANALYSES.

Chemical Analyses of $6\frac{1}{2} \times 1$ in. steel bars. Borings taken from each head after removing surface scale. Pernot open-hearth steel from Cambria Iron Co., of Johnstown, Pa.

Analysis of bars *before annealing.*

	CARBON BY COLOR.	MANGANESE.	SILICON.	SULPHUR.	PHOSPHORUS.	COPPER.
	0.270	0.380	0.036	0.075	0.090	Trace
After annealing...	0.270	0.387	0.031	0.074	0.090	Trace
	ANALYSIS OF EACH HEAD OF SIX EYE-BARS TESTED AT WATERTOWN ARSENAL, MADE FROM ABOVE STEEL.					
M_1 4,582.....	0.300	0.710	0.028	0.092	0.098	0.032
M_2 4,582.....	0.300	0.620	0.023	0.087	0.089	0.030
D_1 4,583.....	0.280	0.730	0.016	0.090	0.097	0.030
D_2 4,583.....	0.280	0.580	0.019	0.085	0.084	0.030
Z_1 4,584.....	0.280	0.650	0.023	0.081	0.092	0.035
Z_2 4,584.....	0.280	0.670	0.014	0.072	0.085	0.030
P_1 4,585.....	0.300	0.640	0.070	0.095	0.093	0.035
P_2 4,585.....	0.300	0.670	0.011	0.072	0.086	0.035
U_1 4,586.....	0.300	0.640	0.011	0.067	0.087	0.040
U_2 4,586.....	0.280	0.650	0.018	0.060	0.081	0.040
L_1 4,587.....	0.280	0.690	0.046	0.074	0.074	0.035
L_2 4,587.....	0.280	0.670	0.011	0.069	0.083	0.030

It is a well-known fact that punching or shearing steel will injure any bar very materially, and the only method of restoring such material to its original condition is to ream out all holes or to plane off sheared edges unless there is an excess of metal at such edge.

To avoid these injurious effects, small holes are punched in steel which are afterward reamed or drilled out to their full size, and the necessity of such a course is represented by the figures subjoined, which give results of tests made on steel bars for the East River Bridge, at Edge Moor Iron Works, by the writer in 1880. These figures also show to what distance from the edge of a hole the

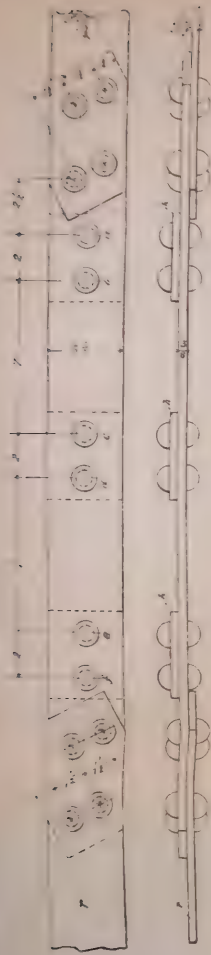


Fig. 2

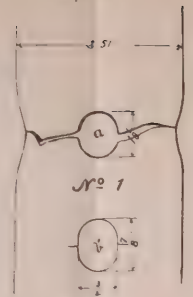
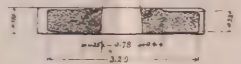


Fig. 4



Holes 1, 2, 3 & in were punched $\frac{5}{8}$ in. diam. & then reamed out to $\frac{3}{4}$ in. diam.; holes a, b, c, d, e, f, were punched $\frac{5}{8}$ in. & not reamed. In this bar no plates "h" were riveted on, and the holes a, b, c, etc. were left open. Elastic limit was reached at 45,655 lbs. per sq. in. At 59,266 lbs. all rivet holes, (punched) showed cracks as indicated at b in Fig. 3.

Bar broke at 58,770 lbs. per sq. in., with fractures, represented in Fig. 4

Rivet holes a-f, elongated as at b, Fig. 3.

Stretch 0.8 in. in 25 in. = 3.2%

Fig. 5

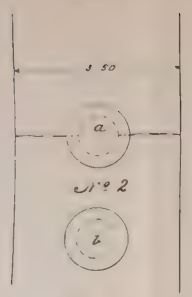
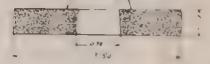


Fig. 6



Holes a-f, punched by "Special Punch" all others reamed.

Elastic limit 56,921 lbs. per sq. in.; broke at 60,641 lbs per sq. in.

This bar showed uniformly large crystals, and did not reduce in section, nor elongate, but broke off suddenly, without giving signs of weakening.

Fig. 7

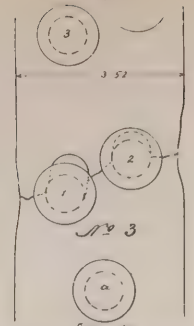
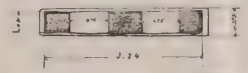


Fig. 8



All holes "reamed" after punching holes with $\frac{5}{8}$ in. punch, save to make $\frac{3}{4}$ in. reamed holes.

Elastic limit 55,487 lbs per sq. in.; broke at 80,830 lbs per sq. in.

Stretch was 0.35 in. in $22\frac{1}{2}$ in. = 1.55%

Fracture showed vesicle crystallization at edges of bar, and some concretion at centre. as shown by Fig. 8

Fig 9

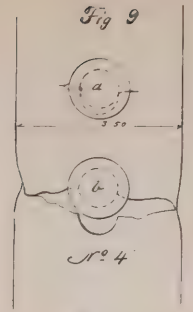
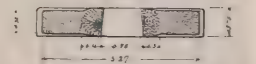


Fig. 10



Holes "a-f," punched by $\frac{3}{4}$ in. punch, all others punched by $\frac{5}{8}$ in. punch, reamed to $\frac{3}{4}$ in. diam.

Elastic limit 55,809 lbs. per sq. in.; broke at 52,604 lbs. per sq. in.

Stretch was 0.6 in. in 24 in. = 2.5%

Fracture showed extremely fine grain, vitrified at the edges, and very coarse crystallization around hole; as shown by Fig. 10. Where bar showed such coarse crystals, no reduction of thickness had taken place.

Fig 11

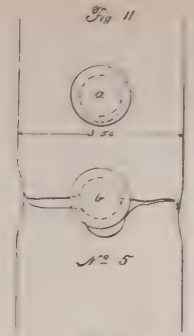
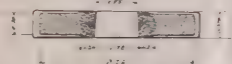


Fig. 12



Holes "a-f," punched by $\frac{7}{16}$ in. punch, all others punched by $\frac{5}{8}$ in. punch & reamed to $\frac{3}{4}$ in. diam.

Elastic limit 53,214 lbs. per sq. in.

Broke at 55,687 lbs per sq. in.

Stretch was 0.5 in. in 24 in. = 2.08%

Fracture was coarse as in No. 4, except there was no brilliancy at edges. See Fig 12.

Tests of Steel Floor-beam-lattice-bars for East River Bridge, made by G. C. Henning. Aug. 19 & 20th 1880

steel is affected by punching, and how much ought to be reamed out to restore the material to its original condition.

TABLE OF PHYSICAL TESTS.

Steel for East River Bridge.

Physical tests of the same steel made on $\frac{3}{4}$ in. round rolled bars made from test ingots.

No. of heat.	Diameters.		Area.			Elastic Limit.	
	Original.	Fract'ed.	Original.	Fract'ed.	% Reduction.	Load applied.	Lbs. per □ in.
a 3,424	.746	.550	.4371	.2376	45.66	21,000	48,040
b 3,424	.747	.505	.4383	.2003	54.20	18,500	42,210

Ultimate Strength.		Elongation.		Modulus of Elasticity.
Lbs. applied.	Lbs. per □ in.	Actual in 8 in.	% of 8 in.	
a 31,975	73,150	1.79	22.37	28,210,000
b 30,450	69,470	2.05	25.62	29,210,000

a was not annealed; *b* was annealed.

These experiments also tend to show that in most cases the punches used have been too large in relation to the size of finished holes; when it is remembered how poorly holes punched in pieces longer than twenty feet match when superposed, it will be readily seen how imperfectly holes will be reamed when but such a small amount is taken off the edges, as was the case in all of the East River Bridge work, in which many of the most important members were nearly or quite 40 feet long. The inference drawn from these tests must be that it cannot but be very defective work in which all holes were reamed so little.

In better work, holes are reamed out $\frac{1}{4}$ inch measured on the die-side of the material punched, and if in this case the holes are not truly matched they will still be reamed out on their entire circumference. The former method was adopted on all of the work for the superstructure of the East River Bridge, holes reamed $\frac{1}{8}$ inch

on punch side of material, while the second method, holes reamed $\frac{1}{4}$ inch on die side was adopted on all steel bridges designed by Mr. George S. Morison, C. E.

In the first case, a large percentage of the holes were reamed out on one side only and left rough on the other; in the second case, there are but very few holes indeed which have not been reamed at every point: in fact, a careful count showed less than one per cent. of holes not entirely clean.

It has often been remarked that drifting or cold straightening ought not to be tolerated in steel work under any condition or circumstances, and as an example of the extremely injurious effect of such treatment, I will mention the case of the boilers of the Russian imperial yacht "Livadia," which were all condemned, being absolutely worthless and broken by the carelessness or ignorance of the mechanics. These boilers were constructed of low carbon steel, but drifting the holes and setting the edges of the plates at the joints, when cold, actually ruptured the plates so that the hydraulic test could not be applied on account of leakage.

The effect of drifting is shown more plainly in the accompanying illustration, which is taken from an actual case. A few weeks ago a steel plate 26 inches by $\frac{1}{2}$ inch thick, and about 26 feet long, was dropped and badly kinked at one edge near the centre; this kink, produced by careless handling, extended about $5\frac{1}{2}$ inches along the edge, and one inch back from it. At the point of greatest depression, the edge dropped below the general surface of the plate about $\frac{1}{2}$ inch, or about the thickness of the plate. At one end of the distortion, the edge was raised about one-quarter inch above the general surface of plate as shown at right hand end of distortion.

Upon seeing this, the question was asked whether and how this defect could be straightened out without destroying the plate. It is a very easy matter to injure a plate in such a manner, but extremely difficult to restore the plate to its former condition.

As it would be a great waste to condemn such a plate which was otherwise perfect, and it would cause considerable delay to replace it, it was suggested to heat the plate to a dull red and hammer the plate on a flat anvil block with heavy sledges, hoping thus to avoid the deteriorating effect of cold straightening.

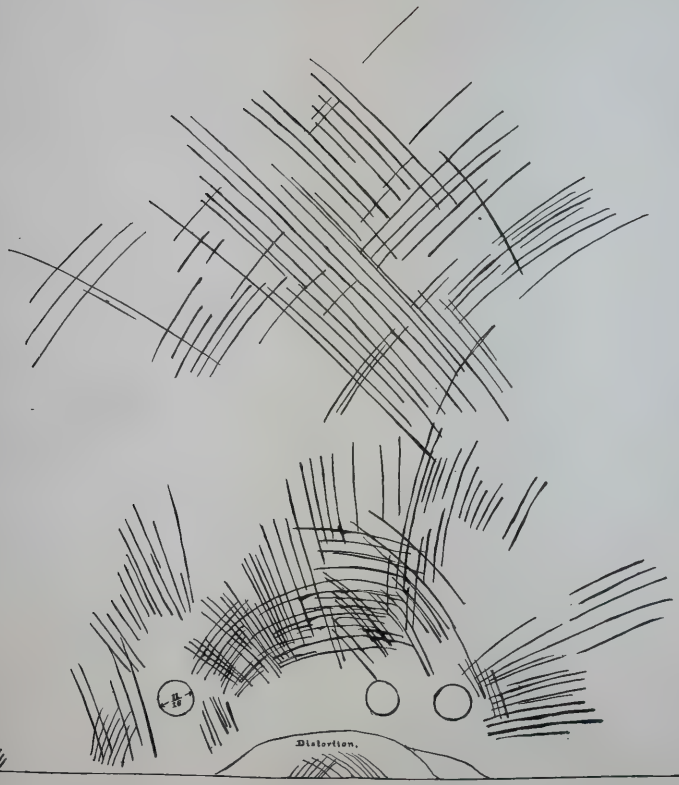
After the job was finished the plate showed marks which the figure represents, also, showing the full width of plate, location of rivet-holes (on die side) and the peculiar lines which can always be traced

26½" Plate.

Lines of Stress

G.C.Henning ME

June 1863.



on steel around a spot which has been overstrained. These lines show where the excessive stress produced by hammering broke off the scale, forming bright lines here indicated in black, and which are of perfectly regular spiral form which it is not difficult to follow.

This straightening was done with the greatest care and precaution, and no trouble spared to do a good job, and still—see the result! Is it to be wondered at that incompetent men will ruin a steel fabrication, or that some "engineers" say that steel is unfit as a material of construction.

But there is a remedy for all this, which must be plain to all, and can be best expressed by the old proverb, "Prevention is better than cure." Start the work correctly in the first place, use nothing but straight shapes, and condemn all abuse and carelessness, however slight, and half the battle is won; but let the bad practices once obtain for ever so short a time and it will be impossible to break them.

These remarks and tests tend to show several things in regard to fabrication of steel work, namely: "Steel eye-bars can be made perfect in every respect, much superior to those of iron: and methods used in shops at the present time must at an early day be superseded by such as will insure better work." An additional point of the greatest importance is this; with current prices of labor and material, not only in Pittsburgh, but in Eastern shops as well, steel work is a little cheaper than iron for all large structures. The ultimate strength of steel, such as is commonly used for structural purposes, is to that of iron as 100 : 71, or as 100 : 65 when comparing the elastic limits, while the relative cost of steel to iron, as taken from contract prices obtaining at present is as 100 : 74. Thus basing all calculations of parts on the elastic limit of the material and the cost on current prices, the relative cost of an iron and steel structure for the same work, will be as $\frac{65}{100} : \frac{100}{74} = 85.8 : 100$, not considering a smaller freight account, there being less material in the work; nor cheaper erection, work being less cumbersome.

TENSILE TESTS OF STEEL EYE-BARS.

BY

GUS. C. HENNING. M.E.

WATERTOWN ARSENAL, MASS.,
June 12, 1883.

Report of Mechanical Tests made with the 400 *ton U. S. Testing Machine.*

Tests made by James E. Howard. No. 4582.

Sectional area, 6.35 □″; *gauged length*, 160 *in.*

Loads Applied.		In Gauged Length.		Elongation.	Remarks.
Lbs. Total.	Lbs. per □ in.	Elongation.	Set.	Centre to Centre of Pins.	
6,350	1,000	0	.....	0	Bar 6.48″ × 0.98″.
31,750	5 000	0.0265	.....	0.06	
63,500	10,000	0.0551	.....	0.12	Head. Diam. Thickness. Pin diam. Width back of pin.
.....	1.000	.....	0.0015	0.015	
95,250	15,000	0.0825	.....	0.17	M_1 14″.00 1″.07 5″.02 5″.55
					M_2 13″.98 1.00 5.03 5.64
127.000	20,000	0.1094	.....	0.23	
.....	1,000	.....	0.0016	0.02	
158,750	25,000	0.1363	.....	0.28	Bar 221.88 in. c. to c. of pin holes.
.....	1,000	.....	0.0018	0.035	
160.000	.....	0.1373	.....	.....	
165,000	.....	0.1420	.....	.....	
170,000	.....	0.1464	.....	.....	
175,000	.....	0.1504	.....	.....	
180.000	.....	0.1548	.....	.....	
185.000	.....	0.1590	.....	.....	
190,000	.....	0.1632	.....	0.34	E = 29,880,000.
.....	1,000	0.0025	.....	0.05	
192,000	.....	0.1648	.....	.....	
194.000	.....	0.1664	.....	.....	
196,000	.....	0.1680	.....	.....	
198,000	.....	0.1700	.....	.....	
200,000	.....	0.1715	.....	0.36	
202.000	.....	0.1730	.....	.....	
204.000	.....	0.1750	.....	.....	
206.000	.....	0.1764	.....	.....	
208,000	.....	0.1782	.....	.....	
210,000	.....	0.1800	.....	0.39	
212,000	.....	0.1818	.....	.....	
214.000	.....	0.1832	.....	.....	
216,000	.....	0.1850	.....	.....	
218.000	.....	0.1865	.....	.....	
220,000	.....	0.1882	.....	.....	
222.000	35.000	0.1900	.....	0.43	
.....	1,000	.....	0.0020	0.09	
224.000	.....	0.1920	.....	.....	

Loads Applied.		In Gauged Length.		Elongation.	Remarks.
Lbs. Total.	Lbs. per □ in.	Elonga. tion.	Set.	Centre to Centre of Pins.	
226,000	.....	0.1934	.....	.....	
228,000	.....	0.1955	.....	.....	
230,000	.....	0.1975	.....	.49	
232,000	.....	0.1994	.....	.....	
234,000	.....	0.2012	.....	.....	
236,000	.....	0.2033	.....	.....	Elastic limit.
238,000	37,480	0.2055	.....	.....	
240,000	.....	0.2100	.....	0.56	
242,000	.....	0.2160	.....	.....	
244,000	.....	0.2233	.....	.....	
246,000	.....	0.6170	.....	6.18	
248,000	.....	1.5400	.....	2.22	
254,000	40,000	2.3700	.....	3.15	
.....	1,000	.....	2.10	2.72	5 minutes rest given bar, at which time the bar had recovered 0.0015 in. additional. Set now being 2.0985 in. New readings taken within gauged length showing elongations after load of 40,000 lbs. per □ in. had been applied.
.....	1,000	0	.....	.....	
.....	5,000	0.0260	.....	.....	
.....	10,000	0.0575	.....	.....	
.....	15,000	0.0875	.....	.....	
.....	20,000	0.1180	.....	.....	
.....	25,000	0.1500	.....	.....	
.....	30,000	0.1830	.....	.....	
.....	1,000	.....	0.0020	.....	
285,750	45,000	3.45	.....	4.87	
317,500	50,000	4.95	.....	7.02	
.....	1,000	.....	4.60	6.44	
.....	1,000	0	.....	.....	
.....	5,000	0.0262	.....	.....	New readings taken in gauged length showing elongation after load of 50,000 lbs. per □ in. had been applied
.....	10,000	0.0585	.....	.....	
.....	15,000	0.0896	.....	.....	
.....	20,000	0.1218	.....	.....	
.....	25,000	0.1555	.....	.....	
.....	30,000	0.1896	.....	.....	
.....	1,000	.....	0.0013	.....	
349,250	55,000	.....	.....	9.72	
381,000	60,000	.....	.....	13.70	
390,000	.....	.....	.....	14.90	
400,000	.....	.....	.....	16.85	
410,000	.....	.....	.....	19.40	
412,750	65,000	.....	.....	20.30	
415,000	.....	.....	.....	21.50	
419,000	.....	.....	.....	23.37	
0	0	.....	.....	.....	Rested 5 minutes.
420,000	.....	.....	.....	23.87	
421,000	.....	.....	.....	25.15	
422,000	.....	.....	.....	25.90	
423,000	.....	.....	.....	26.70	
424,000	.....	.....	.....	27.45	
425,000	.....	.....	.....	28.40	
426,000	.....	.....	.....	29.20	
427,000	.....	.....	.....	30.18	
428,000	.....	.....	.....	30.80	
429,000	.....	.....	.....	31.45	
429,500	.....	.....	.....	32.25	
430,000	.....	.....	.....	34.30	
430,500	.....	.....	.....	35.85	Ultimate strength.
About 410,000	.....	.....	.....	36.40	Load at time of fracture.
0	0	25".20	.....	.....	15.8%.
.....	.....	.....	.....	35.37	15.9%.

Elongation of pin holes $M_1 = 0.75''$; $M_2 = 1.08''$.

Elongation of ten sections (2.79″ fractured section) 1.69″; 1.65; 1.68; 1.60; 1.91; 1.65; 1.59; 1.48; 1.51; 1.59; 1.55; 1.60; 1.60; 1.55; 1.58; 1.54; 1.50; 1.53; 1.62. Area at fracture, $5.33 \times 0.79 = 4.21$ □ in. = Reduction 33.7%. Fractured 16″ from centre of pin hole M_1. Appearance of fracture silky centre with fine granular metal at sides radiating from centre. The thickening of metal in front of pin hole M_1 and dishing of the heads was such that the under side of the head was flat after the test. Head M_2 was dished concave on the under side; placing an 18″ straight edge along the axis of the bar, showed an opening of the metal at the front side of the pin hole = 0.25″, and at the back side of the pin hole of 0.08″.

Test No. 4583. Sectional Area, 6.33 □″;—Gauged Length, 160″.

Loads Applied.		In Gauged Length.		Elongation.	Remarks.
Total Lbs.	Lbs. per □ in.	Elongation.	Set.	Centre to Centre of pin holes.	
6,330	1,000	0	.....	0	Short kinks in bar, near head D_2.
31,650	5,000	0.0250	.....	0.050	
63,300	10,000	0.0528	.....	0.105	
.....	1,000	.....	0.0028	0.010	
94,950	15,000	0.0800	.....	0.160	Bar 6.46″ × 0.98″.
126,600	20,000	0.1072	.....	0.210	
.....	1,000	.....	0.0039	0.020	
158,250	25,000	0.1340	.....	0.270	
.....	1,000	.....	0.0045	0.025	
160,000	.....	0.1355	.....	.....	
165,000	.....	0.1397	.....	.....	
170,000	.....	0.1440	.....	.....	
175,000	.....	0.1482	.....	.....	
180,000	.....	0.1523	.....	.....	
185,000	.....	0.1567	.....	.....	
189,900	30,000	0.1607	.....	0.32	E = 30,270,000
.....	1,000	.....	0.0050	0.04	
190,000	.....	0.1610	.....	.....	
192,000	.....	0.1630	.....	.....	
194,000	.....	0.1645	.....	.....	
196,000	.....	0.1660	.....	.....	
198,000	.....	0.1680	.....	.....	
200,000	.....	0.1695	.....	.....	
202,000	.....	0.1711	.....	.....	
204,000	.....	0.1730	.....	.....	
206,000	.....	0.1747	.....	.....	
208,000	.....	0.1766	.....	.....	
210,000	.....	0.1781	.....	.....	
212,000	.....	0.1797	.....	.....	
214,000	.....	0.1816	.....	.....	
216,000	.....	0.1831	.....	.....	
218,000	.....	0.1847	.....	.....	
220,000	.....	0.1866	.....	.....	
221,500	35,000	0.1880	.....	0.39	
.....	1,000	.....	0.0050	0.06	

Head.	Diam.	Thickness.	Diam. Pin hole.	Width back of hole.
D_1	13.95	1.08	5.02	5.62
D_2	13.97	1.02	5.02	5.62

bar 221.6 in. centre to centre of pin holes.

Loads Applied.		In Gauged Length.		Elongation.	Remarks.
Total Lbs.	Lbs. per □ in.	Elongation.	Set.	Centre to Centre of pin holes.	
222,000	.....	0.1885	.....	.....	
224,000	.....	0.1903	.....	.....	
226,000	.....	0.1920	.....	.....	
228,000	.....	0.1936	.....	.....	
230,000	.....	0.1957	.....	.....	
232,000	36,650	0.1981	.....	.....	Elastic limit.
234,000	.....	0.2010	.....	.....	
236,000	.....	0.2047	.....	0.46	
238,000	.....	0.2092	.....	.....	
240,000	.....	0.2135	.....	.....	
242,000	.....	0.2177	.....	.....	
244,000	.....	0.2231	.....	.....	
246,000	.....	0.2307	.....	.....	
248,000	.....	0 2457	.....	.....	
250,000	.....	0.8667	.....	1.45	
253,200	40,000	2 23	.....	3.06	
.....	1,000	.....	2.02″= =1.262%	2.63	
.....	1,000	0	.....	.....	New readings taken within the gauged length, showing elongation after load of 40,000 lbs. per □″ had been applied.
.....	5,000	0.0250	.....	.....	
.....	10,000	0.0544	.....	.....	
.....	15,000	0.0835	.....	.....	
.....	20,000	0.1140	.....	.....	
.....	25,000	0.1454	.....	.....	
.....	30,000	0.1780	.....	.....	
.....	1,000	.....	0.0020	.....	
.....	45,000	3.27	.....	4.28	
.....	50,000	4.67	.....	6.54	
.....	1,000	.....	4.34= 2.712%	5.97	
.....	1,000	0	.....	.....	New readings taken within gauged length, showing elongations after loads of 50,000 lbs. per □″ had been applied.
.....	5,000	0.0256	.....	.....	
.....	10,000	0.0558	.....	.....	
.....	15,000	0.0860	.....	.....	
.....	20,000	0.1175	.....	.....	
.....	25,000	0.1500	.....	.....	
.....	30,000	0 1840	.....	.....	
.....	1,000	.....	0.0021	.....	
348,150	55,000	.....	.....	9.00	
379,800	60,000	.....	.....	12.45	
390,000	.....	.....	.....	13.75	
400,000	.....	.....	.....	15.60	
405,100	64,000	11.13=	.....	.....	Ultimate Strength.
0	0	.....	.....	15.30	6.956% 6.9%

Elongation of Pin holes $D_1 = 0.66''$; $D_2 = 0.45''$

" " 10″ Sections ;—0.70 ; 0.69 ; 0.70 ; 0.69 ; 0.71 ; 0.70 ; 0.70 ; 0.69 ; 0.69 ; 0.70 ; 0.71 ; 0.69 ; 0.69 ; 0.69 ; 0.69 ; 0.70 ; 0.69 ; 0.69 ; 0.70 ; 0.70.

Fractured suddenly without warning, under the maximum load Broke across neck $6\frac{1}{2}''$ from centre of pin hole D_1. Line of fracture $8\frac{1}{4}''$ long. Appearances granular, radiating from a small fire

crack 0.30″ long by 0.05″ deep and a dull spongy spot 0.4″ × 0.3″; surface of fracture serrated in radiating lines. It is probable the fracture began at the fire-crack corner and tore across the neck. Evidence of this manner of fracture is furnished by the marks near the middle of the fractured surface of the long end of the bar, made by blows on the corner of fracture opposite side with fire crack, of head D_1, during recoil after fracture, the head swinging around.

Test No. 4583A.

Bar D_1 D_2 rested five days between tests No. 4583 and 4583A.

End D_2, secured by its pin.

" D_1, " between flat steel dies.

Gauged length same as in experiment No. 4583, covering 160″ of original length. Actual present length 171.13″.

Load Applied.		In Gauged Length.		Elongation.	Remarks.
Total Lbs.	Lbs. per □″	Elongation.	Set.	Centre to Centre of pins.	
6,330	1,000	0	0	. . . . .	
31,650	5,000	0.0258	. . . . .	. . . . .	
63,300	10,000	0.0573	. . . . .	. . . . .	
94,950	15,000	0.0884	. . . . .	. . . . .	
126,600	20,000	0.1192	. . . . .	. . . . .	
158,250	25,000	0.1503	. . . . .	. . . .	
189,900	30,000	0.1815	. . . . .	. . . . .	
6,330	1,000	. . . . .	0.0008	. . . . .	
189,900	30,000	0.1817	. . . . .	. . . . .	
6,330	1,000	. . . . .	0.0010	. . . . .	
221,550	35,000	0.2128	. . . . .	. . . . .	
253,200	40,000	0.2440	. . . . .	. . . . .	
284,850	45,000	0.2750	. . . . .	. . . . .	
316,500	50,000	0.3065	. . . . .	. . . . .	
6,330	1,000	. . . . .	0.0016	. . . . .	
31,650	5,000	0.0268	. . . . .	. . . . .	
63,300	10,000	0.0580	. . . . .	. . . . .	
94,950	15,000	0.0890	. . . . .	. . . . .	
126,600	20,000	0.1200	. . . . .	. . . . .	
158,250	25,000	0.1510	. . . . .	. . . . .	
189,900	30,000	0.1820	. . . . .	. . . . .	
6,330	1,000	. . . . .	0.0013	. . . . .	
430,000	. . . . .	. . . . .	. . . . .	. . . . .	Rapid stretching began.
453,000	71,560	. . . . .	. . . . .	. . . . .	Ultimate strength.
0	0	13.77″ =		8.6 %	

Total elongation of pin hole D_2 = 0.58″.

Total " of 10″ sections: two sections at end D_1 not measured, covered by holder dies; 0.69; 0.69; 0.70; 0.70; 0.70; 0.84; 0.88; 0.90; 0.94; 0.91; 0.92; 0.92; 0.94; 1.00; 1.00; 1.04; 1.30 (2.55″ fractured section).

Area at fracture 5.29″ × 0.76 = 4.02 □″. Contraction = 36.5%.

Fractured 19½″ from center of pin hole D_2. Appearance fine silky with about 10% granular metal at one edge, radiating from center.

Test No. 4583B.

Bar rested two hours between tests No. 4583A and No. 4583B.

Both ends of bar secured between flat steel dies.

Rapid stretching began at 445,000 lbs. tension.

Ultimate strength 456,100 lbs. = 72,050 lbs. per □″.

Load at time of fracture 415,000 lbs.

Total elongation of 10″ sections: First section at end of D_1 not measured; covered by holder dies (3.05″ fractured section), 1.69; 1.50; 1.41; 1.20; 1.22; 1.13; 1.10; 1.15; 1.25; 1.16; 1.11; 1.11; 1.18.

Area of fracture 5.2″ × 0.75″ = 3.9 □″. Contraction of area = 38.4%.

Fractured 25″ from first fracture, or 31½″ from center of pin hole D_1. Appearance fine silky with trace of granulation along middle of fractured surface.

Test No. 4584.

Sectional area = 6.33 □″; *gauged length* = 200″.

Loads Applied.		In Gauged Length.		Elongation.	Remarks.				
Total Lbs.	Lbs. per □ inch.	Elongation.	Set.	Centre to Centre of pins.					
6,330	1,000	0	.....	0	Bar 6.46″ × 98″.				
31,650	5,000	0.0388	.....	0.06					
63,300	10,000	0.0770	.....	0.12	Head.	Diam.	Thickness.	Diam. pin hole.	Width back of hole.
.....	1,000	.....	0.043	0.015					
94,950	15,000	0.1123	.....	0.180					
126,600	20,000	0.1470	.....	0.24	Z_1	14.00″	1.04	5.02	5.55
.....	1,000	.....	0.0059	0.02	Z_2	14.00	1.04	5.02	5.63
158,250	25,000	0.1810	.....	0.30	Bar 262.70″ c. to c. of pin holes.				
.....	1,000	.....	0.0067	0.025					
160,000	.....	0.1830	.....	.....					
165,000	.....	0.1881	.....	.....					
170,000	.....	0.1935	.....	.....					
175,000	.....	0.1995	.....	.....					
180,000	.....	0.2045	.....	.....					
185,000	.....	0.2096	.....	.....					
189,900	30,000	0.2150	.....	0.365	E 29,630,000.				
.....	1,000	.....	0.0072	0.04					
190,000	.....	0.2150	.....	.....					
192,000	.....	0.2170	.....	.....					
194,000	.....	0.2194	.....	.....					
196,000	.....	0.2213	.....	.....					
198,000	.....	0.2235	.....	.....					

Loads Applied.		In Gauged Length.		Elongation.	Remarks.
Total Lbs.	Lbs. per □ inch.	Elongation.	Set.	Centre to Centre of Pins.	
200,000	.....	0.2256	.....	.....	
202,000	.....	0.2280	.....	.....	
204,000	.....	0.2300	.....	.....	
206,000	.....	0.2322	.....	.....	
208,000	.....	0.2343	.....	.....	
210,000	.....	0.2365	.....	.....	
212,000	.....	0.2390	.....	.....	
214,000	.....	0.2409	.....	.....	
216,000	.....	0.2430	.....	.....	
218,000	.....	0.2452	.....	.....	
220,000	.....	0.2474	.....	.....	
221,550	35,000	0.2490	.....	0.44	
.....	1,000	.....	0.0104	0.05	
222,000	.....	0.2500	.....	.....	
224,000	.....	0.2520	.....	.....	
226,000	.....	0.2545	.....	.....	
228,000	.....	0.2566	.....	.....	
230,000	.....	0.2590	.....	.....	
232,000	.....	0.2617	.....	.....	
234,000	.....	0.2644	.....	.....	
236,000	.....	0.2670	.....	.....	
238,050	37,600	0.2703	.....	.....	Elastic Limit.
240,000	.....	0.2732	.....	.....	
242,000	.....	0.2783	.....	0.64	Rapid stretch taking place in stem
244,000	.....	0.2860	.....	0.74	20″ from centre of pins.
246,000	.....	0.3150	.....	0.88	
248,000	.....	0.4910	.....	1.16	
250,000	.....	1.1000	.....	1.78	
253,200	40,000	1.92	.....	2.66	
284,850	45,000	3.91	.....	5.14	
316,500	50,000	5.55	.....	7.38	
348,150	55,000	.....	.....	10.20	
379,800	60,000	.....	.....	14.20	
411,450	65,000	.....	.....	20.40	
419,000	.....	.....	.....	22.82	
0	0	.....	.....	.....	Rested 5 minutes.
420,000	.....	.....	.....	24.30	
422,000	.....	.....	.....	25.24	
424,000	.....	.....	.....	26.17	
426,000	.....	.....	.....	27.10	
428,000	.....	.....	.....	28.30	
430,000	.....	.....	.....	29.25	
432,000	.....	.....	.....	30.50	
434,000	.....	.....	.....	32.10	
435,000	68,720	.....	.....	33.90	Ultimate strength.
414,000	.....	.....	.....	34.50	Load at time of fracture.
0	0	24.67″ =			12.3 %
				33.18 =	12.6 %

Elongation of pin holes $Z_1 = 0.65''$; $Z_2 = 0.73.''$ Elongation of 10″ sections : 1.38 ; 1.28 ; 1.25 ; 1.26 ; 1.22 ; 1.22 ; 1.20 ; 1.20 ; 1.21 ; 1.22 ; 1.19 ; 1.26 ; 1.34 ; 1.21 ; 1.20 ; 1.19 ; 1.12 ; 1.15 ; 1.20 ; 1.21 ; 1.32 ; 1.50 ; 1.62 ; (2.50 fractured section).

Area at fracture 5.34″ × 0.78″ = 4.17 □″. Contraction of area, 34.1 %.

Fractured 19″ from centre of pin hole Z_2. Appearance of fracture silky 70%, with fine granular metal 30% at sides radiating from centre.

Test No. 4585.

Sectional area = 6.20 □″ ; *gauged length* 200″.

Loads Applied.		In Gauged Length.		Elongation.	Remarks.
Total Lbs.	Lbs. per □ in.	Elongation.	Set.	Centre to Centre of Pins.	
6,200	1,000	0	.....	0	
31,000	5,000	0.037	.....	0.07	Bar 6.46″ × 0.96″
62,000	10,000	0.0724	.....	0.13	
.....	1,000	.....	0.0069	0.02	Head. Diam. Thickness. Diam. of pin-hole. Width back of hole.
93,000	15,000	0.1056	.....	0.19	
124,000	20,000	0.1394	.....	0.25	
.....	1,000	.....	0.0074	0.025	P_1 13.90 1.02 5.02 5.60
155,000	25,000	0.1725	.....	0.31	P_2 14.05 1.03 5.02 5.70
.....	1,000	.....	0.0070	0.03	
160,000	.....	0.1780	.....	.....	Bar 261.85″ c. to c. of pin holes.
165,000	.....	0.1834	.....	.....	
170,000	.....	0.1887	.....	.....	
175,000	.....	0.1940	.....	.....	
180,000	.....	0.2000	.....	.....	
185,000	.....	0.2047	.....	.....	
186,000	30,000	0.2060	.....	0.37	E = 29,960,000.
.....	1,000	.....	0.0070	0.045	
188,000	.....	0.2085	.....	.....	
190,000	.....	0.2102	.....	.....	
192,000	.....	0.2128	.....	.....	
194,000	.....	0.2147	.....	.....	
196,000	.....	0.2167	.....	.....	
198,000	.....	0.2190	.....	.....	
200,000	.....	0.2210	.....	0.40	
202,000	.....	0.2233	.....	.....	
204,000	.....	0.2255	.....	.....	
206,000	.....	0.2275	.....	.....	
208,000	.....	0.2300	.....	.....	
210,000	.....	0.2320	.....	.....	
212,000	.....	0.2340	.....	.....	
214,000	.....	0.2363	.....	.....	
216,000	.....	0.2387	.....	.....	
217,000	35,000	0.2404	.....	0.45	
.....	1,000	.....	0.0065	0.07	
218,000	.....	0.2419	.....	.....	
220,000	.....	0.2445	.....	.....	
222,000	35,810	0.2474	.....	0.465	Elastic limit.
224,000	.....	0.2521	.....	.....	
226,000	.....	0.2595	.....	.....	
228,000	.....	0.2850	.....	.....	
230,000	.....	0.3635	.....	0.61	
232,000	.....	0.3781	.....	0.69	
234,000	.....	0.3907	.....	0.81	
236,000	.....	0.4080	.....	0.93	

Loads Applied.		In Gauged Length.		Elongation.	Remarks.
Total Lbs.	Lbs. per □ in.	Elongation.	Set.	Centre to Centre of Pin Holes.	
238,000	.....	1.35	.....	1.99	
240,000	.....	1.87	.....	2.50	
248,000	40,000	2.80	.....	3.57	
279,000	45.000	4.36	.....	5.64	
310,000	50,000	6 25	.....	8.14	
341,000	55,000	.....	.....	11.35	
372,600	60,000	.....	.....	16.10	
397,000	.....	.....	.....	22.70	
0	0	.....	.....	.....	
400,000	.....	.....	.....	24.30	
0	0	.....	.....	.....	Rested 5 minutes.
400,000	.....	.....	.....	24.30	
403,000	65,000	.....	.....	25.90	
405,000	.....	.....	.....	27.20	
408,000	.....	.....	.....	30.40	Ultimate strength.
375,000	.....	.....	.....	31.20	Load at time of fracture.
0	0	24.05	.....	.....	= 12.0%.
.....	.....	.....	.....	30.21	= 11.5%.

Elongation of pin-holes, $P_1 = 0.68''$; $P_2 = 0.064''$; elongation of 10″ sections: 1.01; 0.99; 1.00; 1.00; 1.00; 0.99; 0.99; 1.04; 1.05; 1.03; 1.04; 1.25; 1.44; 1.15; 1.00; 1.02; 1.08; 1.01; 1.00; 1.08; 1.38; (3.50″ fractured section); 1.48; 1.10.

Area at fracture, $5.10'' \times 0.74'' = 3.77$ □″; contraction of area, 39.2%.

Fractured $42\frac{3}{4}$ in. from centre of pin-hole P_2.

Tore apart from one edge; fractured ends brought together, leave an opening on this edge of 0.15″; short surface cracks and blister $1\frac{1}{4}'' \times \frac{3}{8}''$ near edge first fractured.

Appearance, fine silky 70%, fine granular 30%, radiating from centre, for the part last fractured.

Heads were dish-shaped after fracture; edge of pole nearest end of bar raised 0.15″ above 18 in. straight edge, other edge of hole raised 0.05″.

Test No. 4586.

Sectional area = 6.26 □″ ; *gauged length*, 200″.

Loads Applied.		In Gauged Length.		Elongation.	Remarks.
Total Lbs.	Lbs. per □ in.	Elongation.	Set.	Centre to Centre of Pin Holes.	
6,260	1,000	0	.....	0	Bar 6.45″ × 0.97″
31,300	5,000	0.0400	.....	0.08	
62,600	10,000	0.0748	.....	0.14	
.....	1,000	.....	0.0091	0.02	
93,900	15,000	0.1086	.....	0.20	
125,200	20,000	0.1420	.....	0.27	
.....	1,000	.....	0.0093	0.030	
156,500	25,000	0.1755	.....	0.32	
.....	1,000	.....	0.0104	0.03	Bar 262.12″ centre to centre of pin holes.
.....	1,000	.....	.....	.....	Readings taken after fifteen hours rest introduces these figures.
.....	5,000	0.0393	.....	.....	
.....	10,000	0.0740	.....	.....	
.....	15,000	0.1080	.....	.....	
.....	20,000	0.1414	.....	.....	
.....	25,000	0.1745	.....	.....	
.....	1,000	.....	0.0079	.....	
160,000	.....	.....	.....	.....	
165,000	.....	.....	.....	.....	
170,000	.....	.....	.....	.....	
175,000	.....	.....	.....	.....	
180,000	.....	.....	.....	.....	
185,000	.....	.....	.....	.....	
187,800	30,000	.....	.....	0.380	E = 29,670,000.
.....	1,000	.....	0.0075	0.045	
190,000	.....	0.2105	.....	.....	
192,000	.....	0.2128	.....	.....	
194,000	.....	0.2153	.....	.....	
196,000	.....	0.2175	.....	.....	
198,000	.....	0.2200	.....	.....	
200,000	.....	0.2222	.....	0.41	
202,000	.....	0.2250	.....	.....	
204,000	.....	0.2280	.....	.....	
206,000	.....	0.2312	.....	.....	
208,000	33,230	0.2343	.....	.....	Elastic limit.
210,000	.....	0.2390	.....	0.45	
212,000	.....	0.2435	.....	.....	
214,000	.....	0.2476	.....	.....	
216,000	.....	0.2530	.....	.....	
218,000	.....	0.2650	.....	.....	
219,600	35,000	0.3094	.....	0.55	
.....	1,000	.....	0.0810	0.175	
220,000	.....	0.6965	.....	0.98	
222,000	.....	1.32	.....	1.66	
225,360	36,000	1.64	.....	2.07	
231,620	37,000	2.16	.....	2.75	
237,880	38,000	3.08	.....	3.77	
244,140	39,000	3.33	.....	4.21	
250,400	40,000	3.58	.....	4.56	
281,700	45,000	5.33	.....	6.92	

Head.	Diam.	Thickness.	Diam. of pin-hole.	Width back of hole.
U_1	13.90	1.02	5.02	5.60
U_2	13.80	1.04	5.02	5.55

Loads Applied.		In Gauged Length.		Elongation.	Remarks.
Total Lbs.	Lbs. per □ in.	Elongation.	Set.	Centre to Centre of Pins.	
313,000	50,000	7.50	.....	9.75	
344,300	55,000	.....	.....	13.60	
375,600	60,000	.....	.....	20.63	
0	0	.....	.....	.....	Rested 5 minutes.
380,000	.....	.....	.....	21.94	
385,000	.....	.....	.....	23.70	
390,000	.....	.....	.....	25.94	
395,000	.....	.....	.....	28.05	
400,000	.....	.....	.....	31.20	
401,000	.....	.....	.....	32.30	
402,000	.....	.....	.....	34.10	
402,600	.....	.....	.....	35.10	
403,000	.....	.....	.....	36.60	
403,200	64,410	.....	.....	38.25	Ultimate strength.
355,000	.....	.....	.....	40.65	Load at time of fracture.
0	0	32.84″	.....	.....	= 16.4%.
.....	.....	.....	.....	39.56	= 15.1%.

Elongation of pin-holes, $L_1 = 0.70''$; $L_2 = 0.75''$.

Elongations of 10″ sections: 1.39; 1.42; 1.81; 1.79; 1.75; 1.31; 1.62; 1.89; 1.29; 1.12; 1.19; 2.05; 1.90; 1.32; 1.10; 1.45; 1.60; 1.50; 1.19; 1.14; 2.24; (3.58″; fractured section); 1.30; 1.10″.

Area at fracture 4.94″ × 0.64″ = 3.16 □″.

Contraction of area = 49.5%.

Fractured 46½″ from centre of pin-hole L_2.

Appearance, fine silky 100%; opened a seam ⅝″ long near centre of fracture. Heads dished about .08″ concave, measured from an 18″ straight edge.

Test No. 4587.

Sectional area = 6.27 □″; *gauged length* 200″.

Loads Applied.		In Gauged Length.		Elongation.	Remarks.
Total Lbs.	Lbs. per in.	Elongation.	Set.	Centre to Centre of Pins.	
6,270	1,000	0	.....	0	
31,350	5,000	0.0341	.....	0.06	
62,700	10,000	0.0690	.....	0.12	
.....	1,000	.....	0.0045	0.01	
94,050	15,000	0.1025	.....	0.18	
125,400	20,000	0.1365	.....	0.24	
.....	1,000	.....	0.0050	0.015	
156,750	25,000	0.1700	.....	0.31	
.....	1,000	.....	0.0050	0.025	
160,000	.....	0.1733	.....	.....	

Bar 6.46″ × 0.97″

Head.	Diam.	Thickness.	Diam. of pin-hole.	Width back of hole.
L_1	13.65	1.02	5.02	5.55
L_2	14.00	1.03	5.02	5.65

Bar 261.72″ long c. to c. of pin-holes.

Loads Applied.		In Gauged Length.		Elongation.	Remarks.
Total Lbs.	Lbs. per. in.	Elongation.	Set.	Centre to Centre of Pins.	
165,000	.....	0.1784	.....	.....	
170,000	.....	0.1836	.....	.....	
175,000	.....	0.1889	.....	.....	
180,000	.....	0.1945	.....	.....	
185,000	.....	0.1998	.....	.....	
188,100	30,000	0.2030	.....	0.37	
.....	1,000	.....	0.0053	0.03	$E = 29{,}960{,}000$.
190,000	.....	0.2050	.....	.....	
192,000	.....	0.2076	.....	.....	
194,000	.....	0.2095	.....	.....	
196,000	.....	0.2115	.....	.....	
198,000	.....	0.2138	.....	.....	
200,000	.....	0.2160	.....	0.39	
202,000	.....	0.2180	.....	.....	
204,000	.....	0.2200	.....	.....	
206,000	.....	0.2223	.....	.....	
208,000	.....	0.2248	.....	.....	
210,000	.....	0.2265	.....	.....	
212,000	.....	0.2287	.....	.....	
214,000	.....	0.2310	.....	.....	
216,000	.....	0.2330	.....	.....	
218,000	.....	0.2353	.....	.....	
219,450	35,000	0.2368	.....	0.44	
.....	1,000	.....	0.0046	0.06	
220,000	.....	0.2375	.....	.....	
222,000	.....	0.2400	.....	.....	
224,000	.....	0.2420	.....	.....	
226,000	.....	0.2443	.....	0.47	
228,000	.....	0.2470	.....	0.49	
230,000	.....	0.2500	.....	0.505	
232,000	.....	0.2524	.....	0.51	
234,000	.....	0.2553	.....	.....	
236,000	.....	0.2580	.....	0.535	Elastic limit.
238,000	.....	0.2618	.....	0.55	
240,000	.....	0.2675	.....	0.58	
242,000	.....	0.2736	.....	0.61	
244,000	.....	0.9800	.....	1.60	
246,000	.....	1.28	.....	1.96	
250,800	40,000	2.31	.....	3.06	
282,150	45,000	4.00	.....	5.21	
313,500	50,000	5.75	.....	7.56	
344,850	55,000	.....	.....	10.30	
376,200	60,000	.....	.....	14.70	
390,000	.....	.....	.....	17.00	
400,000	.....	.....	.....	19.50	
410,000	.....	.....	.....	22.65	
0	0	.....	.....	.....	
420,000	.....	.....	.....	27.00	
425,000	.....	.....	.....	30.45	
426,000	.....	.....	.....	31.70	
427,000	.....	.....	.....	32.90	
428,000	.....	.....	.....	34.50	
428,200	69.290	.....	.....	35.45	Ultimate strength.
380,000	.....	.....	.....	36.10	Approximate load at time of fracture.
0	0	27.79	.....	.....	= 13.9%.
.....	.....	.....	.....	35.23	= 13.5%.

Elongation of pin-holes $L_1 = 0.80''$; $L_2 = 0.58$.

Elongation of 10″ sections :—1″.53 ; 1.25 ; 1.40 ; 1.43 ; 1.31 ; 1.31 ; 1.28 ; 1.25 ; 1.26 ; 1.21 ; 1.28 ; 1.45 ; 1.52 ; 1.21 ; 1.15 ; 1.15 ; 1.11 ; 1.10 ; 1.05 ; 1.12 ; 1.50 ; (3.70″ fractured section) 1.64 ; 1.25.

Area at fracture $5.02'' \times 0.72'' = 3.61 \square''$; contraction of area $= 42.4\%$.

Fractured 43″ from centre of pin-hole L_2 ; appearance, fine silky with slight granulations.

F. H. Parker,
Major of Ordnance, Commanding.

Correct: I. E. Howard.

DISCUSSION.

The President.—Discussion on this paper is in order. The Chair will remark that the subject discussed by Mr. Henning is one of very great importance. It was his pleasure to be present during the experiments on the Keystone eye-bars that he speaks of, and the results obtained there were regarded by himself and by all others who were familiar with them as extraordinary. He is very much pleased to know that Mr. Henning is able to give them to the Society.

In regard to punching steel, I have recently been making some experiments at Watertown, and this matter of the relative values of drilled and punched holes I propose to investigate fully, as far as boiler work is concerned.

Mr. Henning speaks of welded eye-bars. We have found that it was possible, in the construction of boilers, to make man-hole nozzles of three-quarter-inch steel. These nozzles which are some eighteen inches in diameter as arranged for a seven-foot boiler, can be welded perfectly, and flanged out so as to make a perfect top flange, with the bottom flange curved to suit the boiler.

Mr. Henning.—Those flanges are about an inch and three-quarters or two inches wide, are they not ?

The President.—About two inches and a half wide, and some three inches wide. I have used steel made by the Cleveland Steel Company, by Naylor & Co., and by the Nashua Iron & Steel Company, and I have no doubt that the steel made by Mr. Wellman will do the same thing. We have not had the pleasure of trying that yet—and we have not had any difficulty whatever in man-holes for boilers, tested with 225 pounds cold pressure.

Mr. Henning.—The Continental Iron Works, in Brooklyn, weld all the government torpedoes, which are about twenty-eight inches in diameter, and flanged all around. They could never do it satisfactorily with iron; they do it with steel easily.

The President.—We also have welded the butt straps surrounding the boiler for the external seams, which are some eight and a half inches wide and seven feet in diameter. Those have always given good results. And the success attending the welding of those butt straps suggested to the Chair that it was possible to make a boiler with all the horizontal seams welded, making them in telescopic form, from four to six feet wide. I believe that is entirely practical, if anybody is willing to pay for it.

Mr. Henning.—The Continental Iron Works are doing it now, and with great success.

Mr. Le Van.—The gentleman stated in his paper that the difference between punched holes and drilled holes was in favor of the drilled holes. Did he have reference to boiler plates?

Mr. Henning.—As to the cost of punching and drilling?

Mr. Le Van.—Yes, sir.

Mr. Henning.—It depends, probably, somewhat upon the thickness of the plate; but, as a rule, in boiler work—say in a $\frac{3}{8}$-inch plate—it would probably be better to drill after the plates are matched and bolted in place, for several practical reasons. First, the holes must be perfectly true, and about the only way to get them true is to put the rims together and drill them true in place. If it is done otherwise and you leave one hole which is but partially reamed, your plate in riveting up is very likely to split right there, should the rough edge of the hole be nearest the edge of the plate. That is the trouble in boiler plates, which would be different from bridge work, where your material is almost always straight; in the best designs bent or curved detail is always avoided, as with a little thought straight short pieces can be employed to advantage.

Mr. Le Van.—I would state that the Baldwin Locomotive Works, of Philadelphia, have just finished three steel boilers for a client of mine, in which the holes were first punched and afterward reamed to receive the rivets. In the four previous boilers built to my order, the holes were drilled in the sheet, and we found that with the greatest care we could not make the holes match. As a consequence, the holes had to be reamed and a rivet of larger size used. Therefore, in the last three boilers we concluded we would

punch all the holes an eighth of an inch less in diameter than the size of the rivet to be used, and then all plates were brought well together in place, and the holes were reamed out to the proper size. We found by comparing the cost with that of the drilled plates that we made a difference of twenty per cent. in favor of the punched holes reamed. From the above we found that punched holes in steel plates of a smaller diameter than the rivets and reamed will be cheaper and better than drilled holes, as the reaming removes the upsetting and hardening around the edge of the holes, due to the punching of steel. Iron plate that is not improved by punching is not a proper material to enter into boiler construction.

Mr. Henning.—When I speak of drilled holes I do not refer to holes drilled in each piece separately and then put together because it is almost impossible to get the holes to match when you superimpose one on the other. We hold the plates together, with bolts not more than fifteen inches apart, and often less, and the plates are so straight and flat that there is no space between them; we cannot get a knife edge or a sheet of paper between the plates, all pieces having been straightened hot before assembling. We ream out or countersink the top and bottom edges of each hole so as to form a fillet under the heads of the rivets. We have found that to be absolutely necessary. Without that I know that more than eighty per cent. of the rivets are not perfectly tight; but with this filleting I have not found one-half per cent. of rivets not perfectly tight.

Mr. Le Van.—You have reference not to boiler work, but to bridge work?

Mr. Henning.—To bridge work; yes, sir.

Mr. Le Van.—I am speaking of boiler work.

Mr. Henning.—The quality of boilers generally depends on how closely plates are packed together. I built several dozen boilers myself some time ago, and I know that I would generally get a tight job if I first saw that the plates were fitted perfectly, so that you could not get anything between. But if you allow the plates to be loose so that you can get anything between, it is utterly useless to try to do anything with them, because you cannot get the rivets down. The only way to get a tight job then is to calk the end, and the calking on the joint around a boiler is merely an additional safeguard. It ought never to be done to get a tight job. The boiler ought to be tight without that calking—the best work will have it that way. (Applause.)

The President.—The Chair will remark, in closing this discussion, that in investigating the matter of drilled *versus* punched holes for a large boiler which he had occasion to construct recently he decided, after reading the reports of the committee appointed by the Institution of Mechanical Engineers of Great Britain, that the punched hole reamed out for boiler work was superior to others; but we made a proviso in each contract that the holes in the plates should be countersunk nearly $\frac{1}{16}$ of an inch on each side, the plates being $\frac{9}{16}$ thick, with rivets $\frac{15}{16}$ in diameter. In testing riveted joints it is impossible to get an accurate idea of the strain that is produced in actual work under steam—from a tensional machine—for the simple reason that the plate is pulled only in the direction of its length, while in the curved plates of the boiler, the strain is the resultant of numerous radial forces, or, to speak more correctly, of pressure acting radially in different directions.

A transverse strain is put upon the riveted specimen when pulled in a tensional machine by the buckling of the outer plates.

A seam that would show a beautiful silky fracture in simple tension, when exposed to transverse strain shows a granular fracture, and that is a peculiarity of steel which has led a great many engineers to think that it was an unsafe material to be used. In a pair of boilers which were made for the city of Boston, for their improved sewerage work, a coupon strip was cut from every plate that was used in the boiler, and I think there were about four plates made for every one that was accepted. We found plates that were apparently made from the same heat that showed, some of them, a granular fracture, and others a beautiful silky fracture. The requirement was 37,000 pounds elastic limit, the ultimate strength not exceeding sixty-five nor less than sixty thousand pounds; and you can see it was necessary to condemn about three plates out of four to get it. The steel was Open Hearth. The parties supposed I had set up a job for somebody else, because of such a hard condition.

Mr. Le Van.—In the last boilers I spoke of, we had coupon strips to accompany each plate. The tensile strength was not to be less than 55,000 nor exceed 60,000 pounds, and have an elongation of 30 per cent. in a section originally twelve thicknesses of the plate. The Otis Steel Company, of Cleveland, furnished the steel, and all the plates came up to the specifications in every respect; there was no plate condemned.

The President.—This was a general specification. We issued

this specification and received bids for the boilers. There was no special brand of steel required. It was open to all bidders. The parties who bid for the boilers supplied their own steel. And I will mention as an incident that the City Engineer of Boston became discouraged after we had condemned a lot of plates, and he got plates from another works who were sure they could furnish material of that kind every time. But they failed to come up to the standard.

I will also state a matter that will be of interest. Mr. Kendall, of Kendall & Roberts, Cambridgeport, told me that of several thousand boilers built of steel, they had never had one fail or give any trouble.

GENERAL INDEX.

Address of Mayor of Cleveland, O., 195.
" memorial of A. L. Holley, 35.
" annual of R. H. Thurston, 75.
Advantages of cambering machine, 114.
" " vertical engine, 378.
Aeronautics, progress in, 94.
Amendment to rules, Com. on, 15.
" offered to rules, 10.
Annual meeting, change of date, 14.
" proceedings of 1882, 1.
Appendix to Bessemer ingot cranes, 245.
" to notes on steel, 415.

Balance cylinder for vertical engine, 376.
Balanced valves, 268.
" vertical engine, 368.
Balancing of straight-line engine, 386.
Bed-plate for vertical engine, 369.
Belting for non-parallel shafts, 165.
Bessemer ingot cranes, 238.
Béton as a building material, 388.
" and iron for H. R. tunnel, 394.
" house struck by lightning, 402.
Bituminous coals, evaporative power of, 249.
Blue limestone as filling for béton, 390.
Boiler explosions early in 19th century, 142.
Boiler explosions, causes of, 143.
Boilers long, support of, 146.
" of the Livadia, 418.
Bower-Barff process for rustless iron, 351.
Breaking block for cranes, 244.
Briggs' scales, 277.
" standards for fittings, 274.
Bridges of long span, 78.
" " steel, 410.
Bridge timber, fractures of, 132.

Cambering machine for rails, advantage of, 114.
Canning (E. W. B.) on A. L. Holley, 39.
Casting flange pipe, method of, 237.
Cast-iron fittings, standards for, 274.
Calking of boiler joints, 429.
Causes of boiler explosions, 143.
Chains vs. ropes in cranes, 295.
Change of date of annual meeting, 14.
Changes of temperature in a béton house, 402.
Circulars of Com. on Commission to test iron and steel, 31.
Clutch couplings, mechanism for, 311.
Coal beds of Penn., classified, 217.
Coal, bituminous, evaporative power of, 249.
Col. Laidley's communication, 20.
Colliery hoisting engines, 218.
" pumps, 220.
Committee, local for N. Y., 1882, 1.
" " " Cleveland, 1883, 193.
" on revision of rules, 15, 199.
" " nomination of officers, 199.
" " gauges and standards, 21
" " test commission, 29.
Communication from Col. Laidley, 20.
Compressed steel, 79.
Compound propeller engines, 213.
Comparison of Johnson's and Meigs' results, 250.
" of vertical and horizontal engines, 385.
Continuous lubrication with grease, 316.
Cored flanges for cast pipe, 237.
Corliss pump valve springs, 349.
Cornish pumps in anthracite mines, 221.
Corrosion of mine pumps, 221.
Cost of béton construction, 398.
" lubrication by grease and oil, 318.
Council, report from, N. Y., 1882, 7.
" " Cleveland, 1883, 198.
Crane for roll trains, 310.
Cranes: A study of types, 288.
" classified, 289.
Crank-shaft, new construction of, 231.
Cross-adjustment of pressure plate of valves, 273.
Crosshead of vertical engine, 373.
Cut-off, best for different pressures, 89.
Cylinder condensation, 88.

Dampness of a béton house, 403.
Dash-pot for drop cut-off, 139.
Davis' piston valve, 268.
Defects of indicator diagrams, 183.
" in steel plate, 418.
Degree of D. E. conferred on E. D. Leavitt, Jr., 204.
Device to ascertain friction of valves, 154.
" to illustrate torsion of springs, 338.

Distortion of castings in Bower-Barff process, 358.
Dome openings in boiler shells, 146, 149.
Double engines for collieries, 220.
Drifting in iron boiler work, 145.
" steel work, 418.
Drums for cranes, 298.
" " colliery hoisting engines, 220.
Dues from members, 8.
Dynamometer, improved form of, 227.

Early colliery engines, 218
" propeller engines, 212.
Economy of lubrication, 315.
" at different pressures of steam, 89.
" of variable cut-off, 136.
Edison's quadruplex telegraphy, 330.
Effect of prolonged stress on iron, 224.
" " sulphur in coal on rustless iron, 363.
Efficiency of the steam engine, 89.
Electric Railways, 86.
Electric Units, 87.
Electricity, progress in, 85.
Endurance of spiral springs, 345.
Engine foundations of re-enforced béton, 395.
Engines, vertical, balanced, 368.
Engineering design, 81.
Eye-bars of steel, 411.
" " tests of, 412.
Evaporative power of bituminous coals, 249.
Excursions at Cleveland, 205.
" " New York, 21.
Experiments by Escher, 90.
Extension of spiral springs, 347.

Fire-proof construction, 399, 401.
Force to slide a valve on its seat, 150.
Formulæ for friction of valves, 162.
" for helical springs, 341.
Foundations of engines in béton, 395.
Frames for cranes, 300.
Frischen's multiplex telegraphy, 322.
Friction of valves under inelastic fluids, 159.
Furnace best fitted for bituminous coals, 257.
Fund for publication, 10.

Gauge Committee's Report, 21.
Gintl, originator of multiplex telegraphy, 321.
Girders for cranes, 300.
Gray's harmonic multiplex telegraphy, 332.
Grease for lubrication, 315.
Grouting under engine bed-plates, 380, 382.

Harmonic system of multiplex telegraphy, 332.
Hoisting engines for collieries, 218.
" gear for cranes, 291.
Holley, A. L., and Zerah Colburn, 49.
" " and Colburn's permanent way, etc., 52.
" " and steamboat inspection, 57.
" " and the Stevens battery, 61.
" " and traction engines, 56.
" " as locomotive engineer, 46.
" " as journalist, 50.
" " as lecturer at Columbia College, 69.
" " at school, 36.
" " birth of, 35.
" " begins treaty for Bessemer patents, 64.
" " compositions of, 41.
" " early inventions of, 44.
" " letters to, and from his father, 42.
" " married, 48.
" " later patents of, 69.
" " memorial address on, 55.
" " Memorial Committee report, 10.
" " on the *N. Y. Times*, 54.
" " on ordnance and armor, 63.
" " on technical education, 67.
" " published papers of, 68.
" " rail-joint of, 56.
" " volunteers service in Civil War, 60.
" " work of on Test commission, 69.
Hydromechanics, progress in, 81.

Incombustibility of béton, 388.
Indicator, new, for engines, 182.
" under varying loads, 188.
Ingot cranes, cylinder and mast for, 242.
" " breaking block for, 244.
Inspection of boilers, 148.
" " material, 79, 411.
Interchangeable parts in machinery, 80.
Iron made rustless by Bower-Barff process, 351.
Isodynamic curves in beams, 134.

Johnson's & Meigs' experiments compared, 250.

Kinematic models, Reuleaux's, 367.

Laidley, Col., communication from, 20.
Large sections weaker than small, 76.
Lifetime of boilers, axles, etc., 147
Livadia's boilers, 418.
Local committees for N. Y. meeting, 1882, 1.

Local committees for Cleveland meeting, 1883, 193.
Long boilers, support of, 146.
Lubrication by grease and oil, 315.
" cost of, 315.

Machine riveting, 146.
Manchester Steam Users' Assoc., 142.
Marine engine of the lakes, 211.
Mast for ingot cranes, 243.
Materials for springs, 336, 348.
Mechanism for clutch couplings, 311.
Members present at N. Y. meeting, 1882, 5.
" " at Cleveland meeting, 1883, 193.
Method of casting flange pipe, 237.
" " constructing a crank-shaft, 231.
" " coiling springs, 336.
Microscopic study of woods, 131.
" " " metals, 133.
Milling, progress in, 83.
Mine cars, 218.
Mortar resisting fire, 401.
Multiplex telegraphy, 321.

National University, 101.
Nomenclature for crane motions, 208.
Notes on steel, 410.
Note on water-hammer, 404.
Number of coils in a spiral spring, 347.

Objections to cast-iron fittings, 276.
Official vs. private inspection of boilers, 143.
Oxidation of iron by carbonic acid gas, 353.

Parallelism of girders of traveling cranes, 303.
Perkins' steam pressures, 87.
Pillow-block for vertical engine, 370.
Piston speed of Corliss engine, 383.
Plaster of Paris in Bower-Barff process, 359.
Planimeter for indicator, 186.
Practical formulæ for friction of valves, 162.
Price of steel as compared with iron, 419.
Principles for high-speed boats, 92.
Production of steel, 65–78.
Proportions of cement in béton, 391.
Pumps for collieries, 220.
Punched holes in steel, 417, 428.
Push or pull in spiral springs, 345.

Reamed holes in steel, 418, 428.
Recommendations for standard fittings, 276.
Re-enforced béton for engine foundations, 395.
Relation of employers to employed, 96.
Report of Council, 1882, 7
" " " 1883, 198.
" " Treasurer, 1882, 7.
" " " 1883, 201.
" " Holley Memorial Committee, 10.
" " Tellers, N. Y., 18.
" " " Cleveland, 200.
" " Gauges and Standards, 21.
" " Committee on Tests of iron and steel, 29.
Resolution of thanks to R. W. Raymond, 5.
" " " N. Y., 1882, 33.
" " " Cleveland, 1883, 207.
" on death of Peter Cooper, 199.
Reuleaux' Kinematic models, 367.
Revision of Rules Committee, 15, 199.
Rivet holes in steel plates, 430.
Roller mills replacing stones, 83.
Rustless iron by Bower-Barff process, 351.

Sales of United States Bond, 8.
Scheme of industrial organization, 99.
Screw propulsion, 94.
Secondary batteries, 85.
Sectional steam boilers, 91.
Soap as lubricant, 272.
Special large pipe fittings, 282.
Specifications for steel boilers, 430.
Speed of steam vessels, 91.
Spiral grooves avoided on rope drums, 307.
Spiral springs, compressible and tensile, 335.
Spiral springs, formulæ for, 241.
" " in Corliss pumps, 349.
" " limit of extension for, 347.
" " number of coils in, 348.
Springer eye-bars, 413.
Spur vs. worm gear for cranes, 302.
Square shaft vs. wire rope for traveling cranes, 304.
Standard dimensions, 80.
Standards in cast-iron fittings, 282.
Standard taper for pipe taps, 285.
Stark's multiplex telegraphy, 327.
Steam engine practice, progress in, 87.
Steam in Bower-Barff process, 356.
Steam pressure for maximum economy, 88.
Steam pipes, water-hammer in, 404.
Steam pumps in mines, 222.
Stearns' multiplex telegraphy, 327.
Steel bridges, 410.
" by compression, 79.
" eye-bars, 411.
" produced by open hearth process, 78.
" replacing iron, 77.
Straightening rails, 106.

Straight line engine balance, 386.
Stuffing-box for vertical engine, 373.
Subdivision in installing machinery, 233.
Superheated steam in underground pipes, 408.
Support of long boilers, 146.
Systematic promotion of industries, 99.

Table for belts at varying shaft angles, 177.
Table of analyses of bituminous coals, 265.
" " chemical analyses for steel bars, 416.
" " evap. power of bituminous coal (B. & W. tests), 267.
" " fractures of wire, 225.
" " steaming values of bitum. coals, 260.
" " tests of eye-bars, 412.
" " tests of Springer eye-bars, 414.
" " tests of steel for E. R. bridge, 417.
" " transverse strength of spruce, 122.
" " useful per cents. of large and small machines, 236.
Tanks of re-enforced béton, 395, 398.
Telegraphy, multiplex, 321.
Tellers for annual meeting, 6.
" report, N. Y., 1882, 18.
" " Cleveland, 1883,
Temper of spiral springs, 348.
Temperature in Bower-Barff process, 356.
Tensile tests of six eye-bars at Watertown, 415.
Tests of floors in béton house, 393.
" of rent pipe, 406.
" of riveted boiler plate steel, 430.
" of spruce beams, 125–131.
Thanks, resolutions of, 5, 33, 207.
Thermo-electric generation of current, 87.
Time for exposure in Bower-Barff process, 357.
Torpedo boats, 92.
Torsion in spiral springs, 337.
Trade schools, 101.
Transportation, progress in, 84.
Traverse gear for cranes, 294.
Traveling cranes of Appleby design, 305.
Treasurer's report, 1882, 7.
" " 1883, 201.
Trolleys or trucks for cranes, 299.
Tubes protected from corrosion, 363, 364.
Turbines, different forms of, 82.

Valves, balanced, Allen, 270.
" " fitted hot, 273.
" " Porter-Allen, 269.
" " Sweet, 271.
Vertical engines, balanced, 368.
Vibrations of engine foundations, 385

Warming a béton house, 392, 396.
Water hammer in steam pipes, 404.
Water-wheel of ferry boats, 141.
Weight to break ingot cranes, 240.
Welded eye-bars, 413.
Welded man-hole nozzles, 427.
Welded torpedoes, 428.
Whitworth compressed steel, 79.

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